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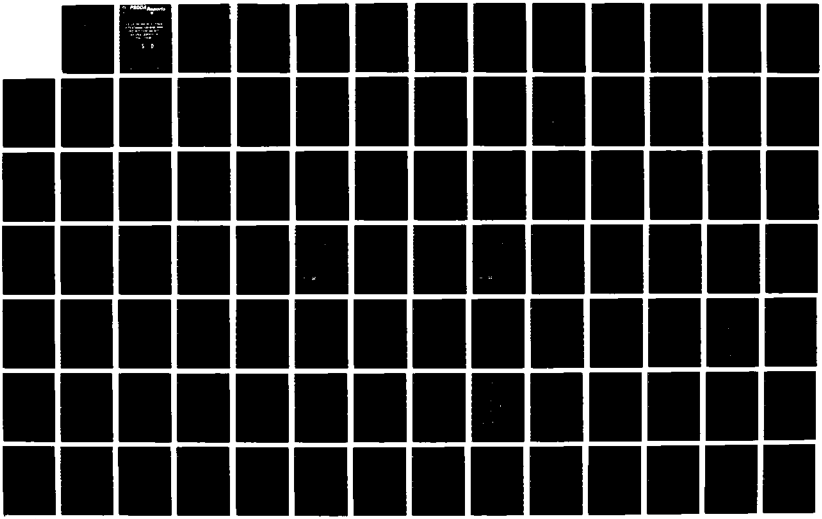

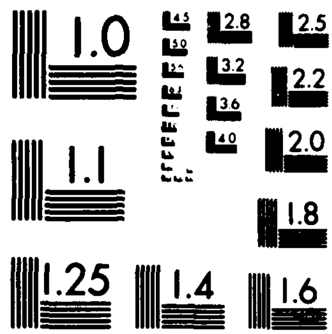

MICROCOPY RESOLUTION TEST CHART

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US Army Corps of Engineers
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PSDDA Reports
Puget Sound Dredged Disposal Analysis

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EVALUATION AND DEVELOPMENT OF Navigation POSITIONING AND MONITORING PROTOCOLS FOR DREDGED MATERIAL DISPOSAL IN PUGET SOUND

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Region 10

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TASK C
EVALUATION AND DEVELOPMENT OF NAVIGATION POSITIONING AND MONITORING PROTOCOLS FOR DREDGED MATERIAL DISPOSAL IN PUGET SOUND

by

Tetra Tech, Inc.

Prepared for

Resource Planning Associates

for

Puget Sound Dredged Disposal Analysis
(PSDDA)

February, 1986

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EXECUTIVE SUMMARY

The Puget Sound Dredged Disposal Analysis (PSDDA) has identified the need to develop protocols for positioning of barges during dredged material disposal operations and for independent verification that disposal activities occur within terms of the disposal permit. This report provides guidance in these tasks by identifying positioning and monitoring methods that can be used at the various disposal sites in Puget Sound.

POSITIONING LIMITATIONS FOR DREDGED MATERIAL DISPOSAL

The purpose of designating dredged material disposal sites is to limit the areas of deposition and biological impact. The ability to position a barge at a disposal site is influenced by maneuverability of the barge/tug combination, limitations of the specific positioning method, and size of the disposal site. Site use requirements, including allowable positioning methods, should be based on all of these factors.

The barge/tug combination does not have sufficient maneuverability for fine-scale positioning and is subject to drift while releasing its load. Therefore, the area within which the larger barges [76 m (250 ft)] can consistently be positioned is limited. A circle with a radius twice the barge length should provide an adequate positioning area for all weather conditions. A highly accurate navigation system [position accurate to within ±1 m (3.3 ft)] would not necessarily be better for this task than a system with one order of magnitude less accuracy.

All positioning methods are subject to inherent limitations of accuracy and to external limitations of the site. The ability of a positioning method to achieve its highest projected accuracy depends on site-specific physical conditions, familiarity of the operator with the positioning method, proper record keeping, and accuracy of the maps used to locate positions from fixes. Minimizing these sources of error provides greater probability

that users are located within the dump zone. The area of probable location that can be resolved by a navigation method (the radial error) varies with location because of changes in the geometry of the fix points and vessel. The number of objects or targets with known locations that can be used for a position fix is dependent upon the method used and, in some cases, on the surrounding physical terrain. Locations of the disposal sites that will be utilized during Phase I and II of PSDDA should be determined before recommendations are made on positioning methods and dump zone sizes.

The limitations imposed by barge maneuverability and positioning error can be used to determine the appropriate size of the disposal site to ensure compliance with disposal guidelines. A small user zone should be specified within the disposal site in navigation coordinates of an acceptable positioning method. Barge location area can be defined by 1) calculating the radius of the circle in which the barge is probably located and 2) increasing the radius of the specified user zone area by that calculated radius. If the tug were within this user zone set of coordinates, the barge would be within the disposal site boundary. Violations under these conditions would probably not be due to navigation system error, but to a deliberate act or user error.

POSITIONING METHODS

Methods presently used in Puget Sound to position barges at disposal sites cannot consistently place the barge within dump zone boundaries. Potential alternative positioning methods were evaluated. Some were eliminated from further consideration because of overly restrictive limitations, including the inability to operate at night or in limited visibility and availability of similar, less expensive methods. The remaining methods were grouped into accuracy categories of $\pm$20-30 m ($\pm$66-99 ft) and $\pm$2 m ($\pm$6.6 ft) for determination of dump zone boundaries. Variable range radar and Loran-C systems constitute the former category. Microwave and satellite systems constitute the latter category. For $\pm$20-m ($\pm$66-ft) accuracy methods, a 244-m (800-ft) radius site boundary should be adequate to compensate for positioning error and drift. In areas of stronger tidal currents (exceeding 1 kn), a 274-m (900-ft) radius dump zone would be more appropriate. For

±2-m (±6.6-ft) accuracy methods, a 213-m (700-ft) radius site should be adequate for most locations, with an increase of 31 m (100 ft) in areas of higher tidal currents. A smaller circle within the site should be designated as the actual disposal zone for users. Coordinates of this area should be determined on site by the method that will be required of users. The minimum radius of the inner user zone area should be 120-180 m (394-590 ft) to allow for barge positioning limitations. Elastically moored buoys can also be used to mark disposal sites. The site radius associated with this positioning aid is comparable to that associated with ±2-m (±6.6-ft) accuracy methods.

Site-specific characteristics that could limit barge positioning at the existing and potential disposal sites in Puget Sound are addressed in the following alternative recommendations:

1. **Use both Loran-C and VRR at all sites.** This will require the regulatory agency to determine positioning coordinates in Loran-C and VRR for each site, after comparing Loran-C and VRR coordinates with those of a microwave system or a similar high absolute accuracy method. The use of both Loran-C and VRR systems (common equipment to most tugs) allows VRR fixes to be used at sites with consistent or periodic Loran-C interference. Boundaries may be reduced to a 244-m (800-ft) radius at sites with low currents and Loran-C coverage or adequate proximity to shore for accurate VRR fixes. A 244-m (800-ft) radius is also acceptable at deeper sites with low currents at which depositional area must be carefully restricted. Boundaries should be kept at 274 m (900 ft) at sites with strong tidal currents, at sites without Loran-C coverage and long ranges for VRR fixes, and at sites that can have severe wind and wave conditions.

2. **Use Loran-C and VRR until GEOSTAR or GPS satellite systems become cost-effective.** Satellite systems will allow reduction of the disposal boundary radii suggested in Alternative #1 by 31 m (100 ft). They can be used at any site and will

be as easy to operate as Loran-C. Satellite positioning methods are expected to become the common method of navigation and costs are expected to decrease. Until that time, Loran-C and VRR should be used as specified in Alternative #1.

3. **Use elastically moored buoys at appropriate sites, and Loran-C and VRR at the other sites until satellite systems become cost-effective.** Until satellite systems are more practicable, elastically moored buoys can be used for positioning where it is especially important to restrict depositional area. These might include high-use sites, deeper sites, or ones with high tidal currents causing large drift. At less frequently used sites, Loran-C and VRR could be used to reduce the number of buoys and the associated costs.

MONITORING METHODS

Various methods to monitor disposal operations were evaluated to identify methods that could be used at disposal sites in Puget Sound. Some methods were eliminated from consideration because of limitations including the inability to monitor in restrictive visibility and high logistical costs. Site user records and U.S. Coast Guard Vessel Traffic Service (VTS) Radar monitoring would be the easiest programs to implement. Remote monitoring methods would be more expensive and labor-intensive.

Site-specific characteristics that could limit monitoring at existing and potential disposal sites in Puget Sound are addressed in the following alternative recommendations:

1. **Require operator record keeping at all sites and spot-check with shore-based operations.** This requires the regulatory agency to determine the positioning coordinates and fixes for each site. The coordinates reported by the user can be compared with those of the dump zone to determine whether the barge was within the boundaries at the start and end of the dumping operations. Shore-based observations with

theodolites (two operators and communication), total stations (one operator), or range-azimuth systems (one operator) would be needed to perform random spot checks to discourage noncompliance. Optical resolution (theodolites and some total stations) may be a limiting factor for some sites. Single-station methods logisitically are simpler to use and have fewer visibility restrictions, but will require multiple prism assemblies on disposal barges. Presence of the prisms on the barges may encourage more careful and honest record keeping.

2. **Use VTS Radar coverage where available and supplement with spot checks of other sites.** The appropriate regulatory agency will have to coordinate with the U.S. Coast Guard on positioning procedure and documentation. Position fixes at the start and the end of the dump should be required. Only four of the existing disposal sites can be monitored by VTS. VTS Radar can be used at these sites for positioning and the regulatory agency will not need to determine site positioning coordinates. The remaining sites must be monitored by the procedure noted in Alternative #1. The same records should be required for all sites.

3. **Use a remote monitoring system and supplement with spot checks.** This alternative will require the agency to determine positioning coordinates and fixes for each site. Some sites experience sporadic or persistent interference of the Loran-C signals. Such problems should be eliminated by switching to satellite signals when they become available. The system appropriate to PSDDA needs will have to be determined. Placement of the monitoring unit on the barge and the part-time monitoring at these sites might be adequate to produce consistent compliance; otherwise these sites must be spot-checked using procedures in Alternative #1. The same records noted in Alternative #1 should be required for all sites.

INTRODUCTION

The Puget Sound Dredged Disposal Analysis (PSDDA) is an interagency effort to develop guidelines for assessing environmental effects of dredging and dredged material disposal operations. This effort includes the development of protocols for positioning barges disposing of dredged material. This effort also includes the development of methods to independently verify that disposal activities comply with the terms of the disposal permit.

PURPOSE

The purpose of this report is to provide guidance for disposal site management by identifying:

- Positioning accuracy that can reasonably be expected of barge operators, including positioning methods that can achieve the expected accuracy and associated marginal costs

- Remote monitoring methods that can be used in Puget Sound to verify location of disposal activities.

APPROACH

A survey of methods for positioning and remote monitoring of position was performed. Data were collected from literature, manufacturers, and interviews with Puget Sound dredging contractors and tug captains. Information initially was used for two purposes:

- To define factors that limit achievable accuracy in positioning a barge

- To identify positioning methods in use during disposal operations in Puget Sound.

Barge positioning methods were evaluated based upon the following factors:

- Accuracy
- Range capabilities
- Flexibility (i.e., range of conditions under which system can operate)
- Equipment portability
- Calibration and maintenance requirements
- Reliability
- Service and equipment availability
- Cost.

Advantages and disadvantages of each method are presented. Limitations to achieving greater accuracy in Puget Sound are also presented. Positioning methods and the dump zone radii large enough to be used with those methods are recommended for the various disposal sites in Puget Sound.

Methods for monitoring disposal operations were evaluated in a similar manner. Basic requirements for monitoring methods included applicability over a variety of disposal site conditions, real-time monitoring capability, and the ability to detect load release. The factors used to evaluate positioning methods were also used to evaluate monitoring methods. Two other factors were added:

- Level of user training required
- Degree to which monitored events can be documented.

Systems to meet the specific monitoring needs of PSDDA are recommended for the various Puget Sound disposal sites.

POSITIONING LIMITATIONS FOR DREDGED MATERIAL DISPOSAL

The ability to position a barge at a disposal site is influenced by maneuverability of the barge/tug combination, limitations of the specific positioning method, and size of the disposal site. Site use requirements, including allowable positioning methods, should be based on all of these factors. Each factor is addressed in detail below.

BARGE MANEUVERABILITY

Despite the need to minimize the area of impact from dredged material disposal, the dimensions of a designated dump zone must be large enough to accommodate maneuverability limitations if consistent release within the designated dump zone is expected. Barges in Puget Sound range in length from 15 to more than 76 m (50 to more than 250 ft) and most are longer than 40 m (131 ft). Barges generally are not self propelled, but rather are pushed or pulled by tugboats. Maneuverability decreases with increasing distance between the barge's inertial center and the tug. The offset distance between the barge and tug varies with transport method and barge size. Wind, waves, and currents make it very difficult to position a barge at a predetermined location.

Twenty minutes or more may elapse between the time a loaded barge arrives on site and the time it is emptied of dredged material. Most of the material is dumped within 2 to 10 min after the barge doors are opened, depending on the type of barge. Cohesive sediments can take up to 1 h to exit the barge (Preston, K., personal communication). Hopper or bottom door barges usually take longer to empty than do split hull barges. During disposal, maneuverability is extremely limited and the barge may drift outside the dump zone before the process is complete. A current of 26 cm/sec (0.5 kn) could displace a barge up to 30 m (97 ft) in 2 min or 150 m (487 ft) in 10 min. Wind could increase this displacement depending upon the barge's effective surface area and its orientation to the wind.

Both methods of barge transport pose positioning problems. If the barge is towed, it will tend to move across the disposal site during dumping. If the tug slows at the site, the barge may drift. Sometimes the tug will be within the site boundary but the barge will not. Thus, estimation of barge position in relation to the site boundaries (rather than tug position) becomes unreliable.

Five to ten minutes is required for a tug to clear a pushed barge to avoid damage from the barge "jump" when the doors are opened and the load is released. Consequently, the actual dump may not terminate until 20 min or more after a pushed barge has reached the site. Displacement by wind or currents during this period could exceed 300 m (974 ft) in a current of 26 cm/sec (0.5 kn).

In conclusion, the barge/tug combination does not have sufficient maneuverability for fine-scale positioning and is subject to drift while releasing its load. Therefore, the area within which the larger barges [76 m (250 ft)] can consistently be positioned is limited. A circle with a radius twice the barge length should provide an adequate positioning area for all weather conditions. A highly accurate navigation system [position accurate to within ± 1 m (± 3.3 ft)] would not necessarily be better for this task than a system with one order of magnitude less accuracy. Maneuverability limitations and drift are considered herein in recommendations of acceptable positioning systems and dump zone dimensions.

LIMITATIONS OF POSITIONING METHODS

All positioning methods are subject to inherent limitations of accuracy and to external limitations imposed by the site. The concepts of accuracy and error are introduced in this section and site-related limitations are described.

Accuracy and Error

Positioning methods and equipment contribute errors to the overall accuracy of a position fix. Absolute or predictable accuracy refers to a method's ability to correctly define a position by latitude and longitude (Bowditch 1977). Repeatable or relative accuracy measures a method's ability to return the user to the same position time after time. The difference between these accuracies can be significant. For example, depending on one's location in the coverage area, Loran-C has a repeatable accuracy of 15 to 90 m (49 to 295 ft), but an absolute accuracy of 185 to 463 m (607 to 1,519 ft) (Dungan 1979).

In many circumstances, repeatable accuracy is more important than absolute accuracy (e.g., retrieving crab pots, returning to desirable fishing grounds, and locating an important buoy). For disposal operations, both repeatable and absolute accuracy can be important. Initial location of the disposal site depends upon absolute accuracy. However, return to a site depends on repeatable accuracy. Because repeatable accuracy can be one order of magnitude greater than absolute accuracy, the latter will typically be the limiting factor in accurate barge positioning. If the coordinates for a disposal site have been established by a positioning method that will be required of users, the margin of positioning error at that site will be defined by repeatable accuracy rather than by absolute accuracy. Because repeatable accuracy is typically greater than absolute accuracy, a wider range of navigation methods can then meet the positioning accuracy requirements for a given disposal site.

All positional fixes are in error to some extent, as determined by the measurement error in each line-of-position (LOP - the line drawn on a map along which the vessel must lie) and in the crossing angle of the LOPs. This error is commonly described as the probability that the vessel is located within a circle of a specified radius centered at the point where LOPs cross. Equipment manufacturers most commonly quote these circular accuracy probabilities as circular probable error (CPE or CEP) and radial error (d_{rms}). These terms and their calculation are discussed in detail in "The Evaluation of Survey Positioning Methods for Nearshore Marine and

Estuarine Waters" (Tetra Tech 1986). Circular accuracy probabilities can be used to determine the size of any error-of-position circle at a desired probability level or to determine the probability that a measured position is within a circle of a selected radius. The latter can be used to determine whether a navigation method will be able to position a barge within specified dump zone radii.

Site-Related Limitations

The ability of a positioning method to achieve its highest projected accuracy depends on site-specific conditions, familiarity of the operator with the positioning method, proper record keeping, and accuracy of the maps used to locate positions from fixes. Minimizing these sources of error provides greater probability that users are located within the dump zone. Weather, currents, and other site conditions affect the ability to maintain position within the disposal site. Proximity to land and the physical terrain also limit the accuracy of certain methods.

The accuracy of a position fix from any two points increases as the angle between the lines-of-position approaches 90 degrees. The area of probable location that can be resolved by a navigation method (the radial error) varies among locations because of changes in the relative location of the fix points and the vessel. The number of objects or targets with known locations that can be used for a position fix is dependent on the methods used and, in some cases, on the surrounding terrain. An acceptable fix target for one method may not be an acceptable target for another method. A preferred method may not be usable or sufficiently accurate at all locations. For example, Loran-C cannot be used in some parts of Puget Sound and the accuracy of visual sighting methods decreases with distance from shore. Thus, locations of the disposal sites that will be utilized during Phase I and II of PSDDA should be determined before a recommendation is made on positioning methods.

Locatibn has many effects on the accuracy and applicability of various positioning methods. Such effects are described below for optical, radar

range, and short-range and long-range electronic positioning methods. These methods are described because they are commonly used in Puget Sound.

Optical positioning methods rely on the visual resolution of objects with a known position. Built structures provide more accurate fixes than land features because sharply defined objects provide better resolution. The ability to resolve an object decreases with distance. Within 5 km (3.1 mi) of the shoreline and in more developed areas, accuracy of optical methods can be comparable to that of electronic methods. However, optical methods are more dependent upon proper operation and target choice than are other methods. Urban embayments are therefore better suited for optical positioning than are regions in central Puget Sound or areas along less populated, featureless shorelines. The abundance of accurately located channel markers throughout Puget Sound provides good sightings in otherwise featureless areas. On featureless shorelines, a line tangent to shore is used as a line-of-position, with considerable reduction in accuracy. Use of optical methods is restricted to daylight hours of good visibility.

Positioning by multiple ranges measured from a variable range radar system requires fixes on known positions, but eliminates visibility restrictions. However, because the radar signal is shadowed beyond the first object it strikes, the choice of targets can be limited. A second limitation is possible misidentification of reflection sources in developed areas. Positions based on misidentified reflection sources are inaccurately located, but can be reoccupied if the same perceived reflection source is subsequently used. A third target should be used to crosscheck position determined from two other targets. All three fixes should be on the same radar range scale.

Reflections depend on target position and alignment. The most accurate radar range fixes are based on reflections from objects 0.16-6.4 km (0.1-4 mi) distant (Crawford, P., personal communication). At disposal sites farther from shore, adequate targets may not be available. Reflections closer than 0.16 km (0.1 mi) may be erroneous and should not be used. Sloped headlands and tidal flats are not usable as targets.

Short-range electronic positioning systems (e.g., microwave) involve at least two shore stations (transponders) and an on-board transmitter. A set of stations is required for each disposal site. Successful reception of electromagnetic signals is the critical feature for effective operation of electronic positioning systems. Signals from the transponders or shore stations should be received at an angle of 30 to 150 degrees; 90 degrees is optimal. Signal reception is dependent upon electronic "line-of-sight" and may be blocked by tight quarters (e.g., waterways, rivers, and shorelines) and heavy vessel traffic. Such problems are alleviated by newer, more expensive systems that accommodate over a dozen transponders. With proper transponder locations, microwave systems can be used to position a vessel any distance from shore in Puget Sound except closer than 100 m (328 ft) to one of the transponder locations.

Accuracy of microwave systems depends upon placement of the remote transponders or shore stations. For example, remote stations not located on a monumented point will increase error of the vessel position fix. However, access restrictions, benchmark locations, and line-of-site considerations limit the available transponder locations and achievable angles. Permanent shore station locations are further limited by availability of power sources and site security.

Repeatable accuracy of microwave systems, while not affected by transponder location errors, is dependent upon the line-of-position angle. Certain combinations of transponder and vessel locations may result in signal cancellation (range holes) and failure to obtain a fix. Occurrence of range holes varies by location, is impossible to predict, and may force relocation of a shore station. In developed areas, reflections from metal objects or buildings may compound the problem or cause jumps in the received signal.

Long-range electronic positioning systems operate on permanent transmitting stations and user-carried receivers. The only receivable long-range system in Puget Sound is Loran-C. However, because land masses distort signal propagation, Loran-C charts are of unknown accuracy in inland waters such as Puget Sound. In addition, an unidentified electronic source interferes with Loran-C reception in some areas and prevents its use much of the time.

However, Loran-C is accurate for repositioning at locations where readings were recorded in Loran-C on original occupation.

Recent Loran-C maps based on comparison of Loran-C coordinates with those from other methods at the same stations support positioning to a resolution of 0.1 usec of the Loran-C signal [about 37 m (120 ft)] for limited areas in the vicinity of Elliott Bay (Sturgill, D., personal communication). Accurate maps for other areas are not available. Distortion can be defined for areas outside Elliott Bay only by taking readings at benchmarks around the shoreline. Accuracy is less reliable with distance from the benchmarks. Therefore, while Loran-C is usable around Elliott Bay for initial positioning, it can be used in other areas only as a repositioning tool and will require predetermined dump zone Loran-C coordinates for barge positioning.

DISPOSAL SITE RADIUS

The designated dump zone should be as small as practicable to minimize adverse impacts on the marine environment, but not so small as to result in frequent user violations. Minimum practicable dump zone dimensions are affected by two factors:

- The error of acceptable positioning methods

- The area within which the larger barges can reasonably be positioned.

A common problem for positioning within a defined area is presented in Figure 1. A position fix theoretically places the vessel within the disposal site. Due to the error associated with the method, the vessel is actually beyond the boundary.

This problem can be avoided by specifying a small area within the disposal site (the shaded area in Figure 2) as the user dump zone. The area should be described as a range of coordinates in an acceptable positioning method. The barge location can be defined by 1) calculating (at the desired

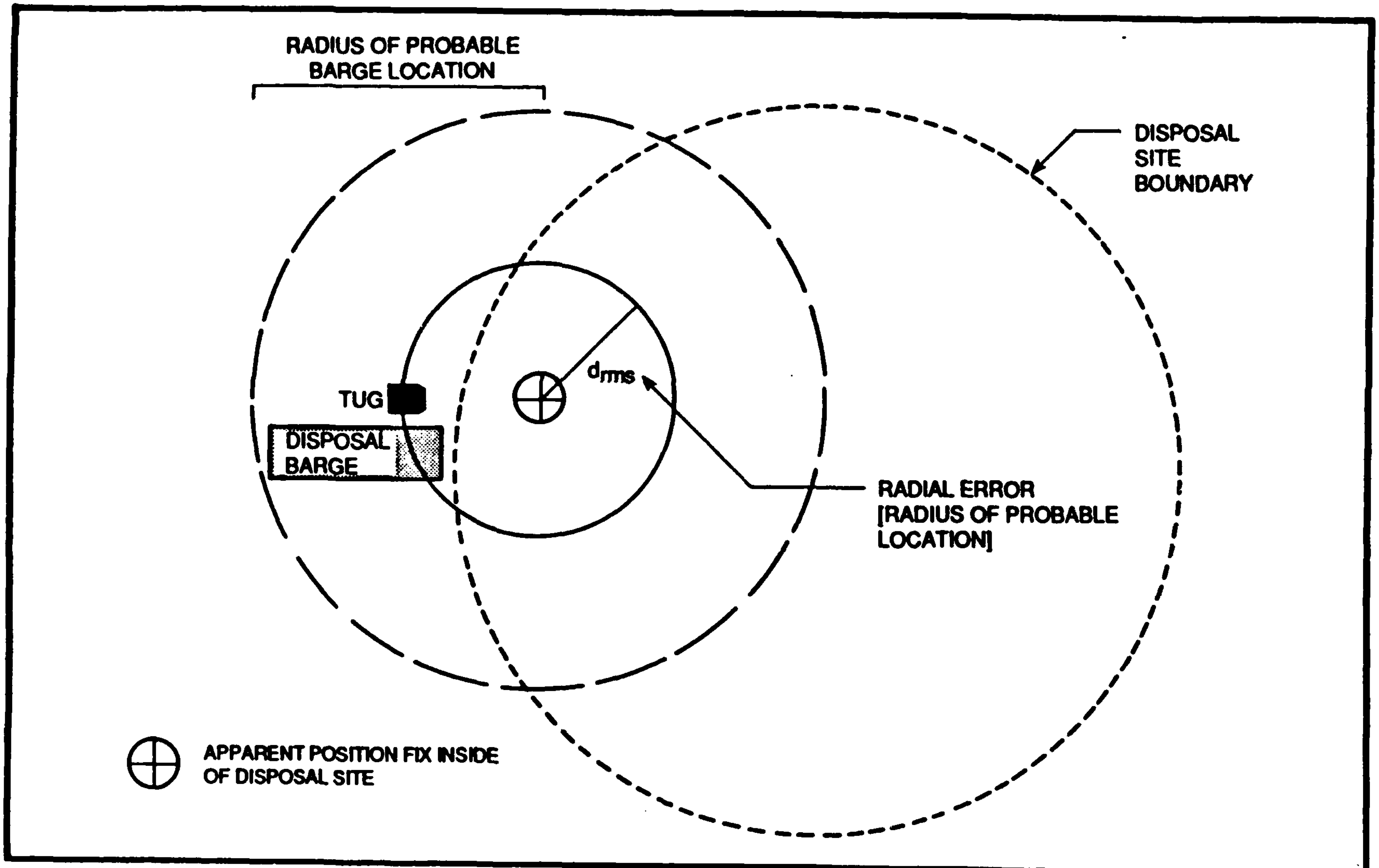

Figure 1. Barge offset and navigational error effects on the probable location area.

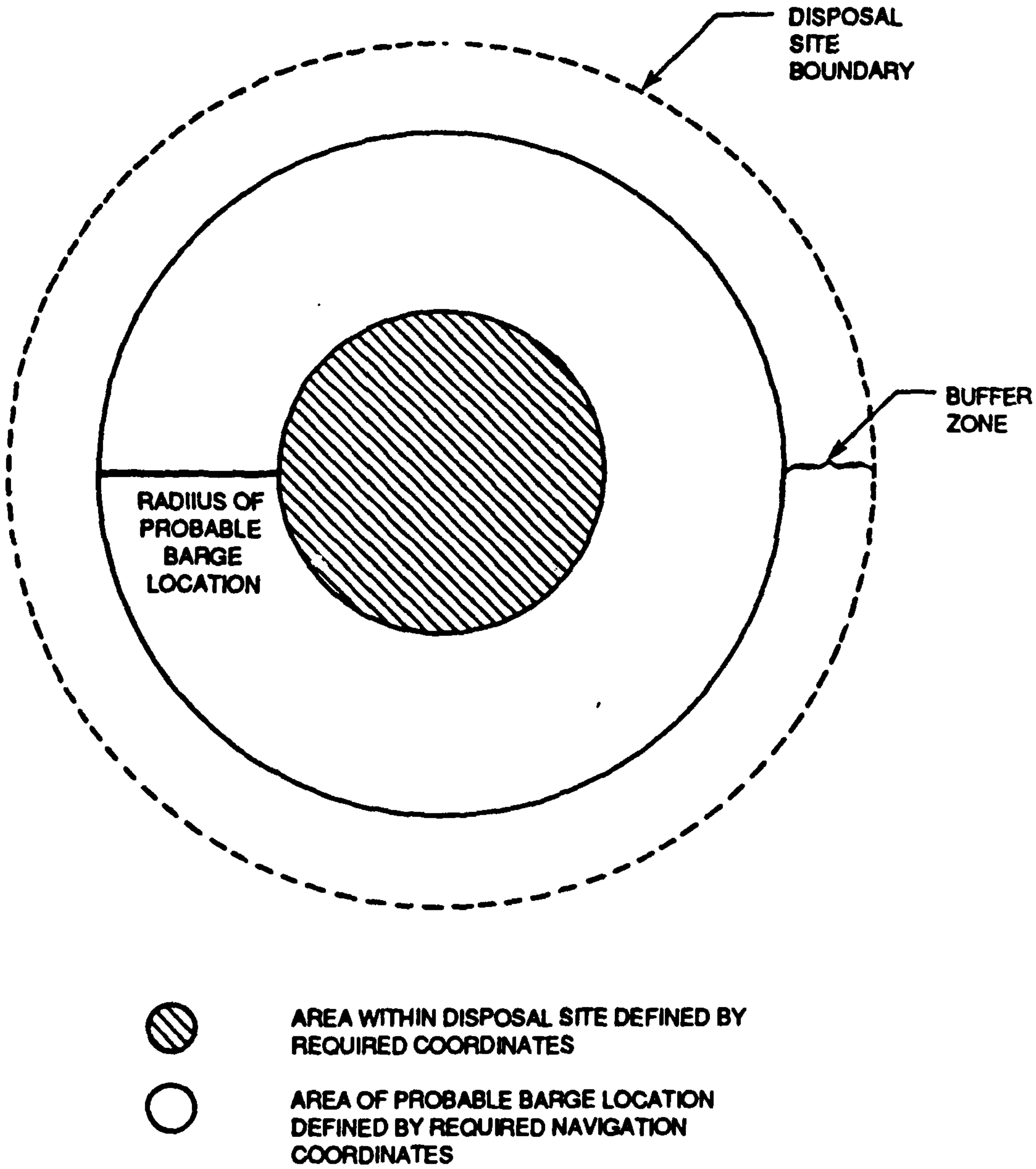

Figure 2. Relationship of site boundary to required navigation coordinates.

level of probability) the radius of the circle in which the barge is probably located (bold line in Figure 2), and 2) increasing the radius of the specified area (shaded in Figure 2) by the radius calculated above. For example, assume Loran-C is an acceptable positioning method, and Loran coordinates between 42063.0 and 42063.4 for channel 1 and between 28690.0 and 28690.4 for channel 2 define the smaller area of the disposal site within which the tug has to be positioned. If the Loran-C readout on the tug were within this set of Loran coordinates, the barge would be within the disposal site boundary. Violations under these conditions would probably not be due to navigation system error, but to a deliberate act or user error. The use of predetermined navigation coordinates to establish disposal site boundaries enables the use of repeatable rather than absolute accuracy on return visits to the site, with a consequent reduction in positioning error.

Site radii can be established to reduce incidence of boundary violations by:

- Sizing the predetermined area to accommodate the least maneuverable barge-tug combination

- Calculating the radius of probable barge location (bold line in Figure 2) at a high probability (i.e., P=0.95 that barge is within calculated area)

- Including a buffer zone beyond the area of probable barge location.

POSITIONING METHODS

Methods to position barges at Puget Sound disposal sites are addressed in this chapter. After an overview of each method is presented, effects of each method on dump zone radius are explained. Available positioning methods are evaluated and recommended minimum dump zone radii are specified. Finally, alternative recommendations for positioning methods for disposal operations in Puget Sound are provided. Positioning methods and associated equipment are described in detail in Appendix A.

POSITIONING PROCEDURES IN USE IN PUGET SOUND

Equipment, procedures, advantages, and limitations of positioning methods used in Puget sound were identified from interviews with Puget Sound dredging and marine construction firms. The various combinations of positioning methods used, the user-reported accuracies, and method limitations are presented in Table 1. Most barge positioning at disposal sites in recent years has been accomplished with radar ranges and visual sightings because:

- Radar is standard equipment on tugs

- Radar is normally used to navigate

- Loran-C is distrusted in inland waters.

Tugs are equipped with radar as standard equipment for safety and navigation. Most experienced captains use radar and visual sightings to achieve absolute positioning accuracies at disposal sites of $\pm$200-300 m ($\pm$656-984 ft), with increasing accuracies closer to shore. Radar on some vessels has been upgraded to variable range markers (VRM), removing a large portion of operator error in estimating distance and bearing to targets, and increasing positioning capabilities to within $\pm$100 m ($\pm$328 ft).

TABLE 1. BARGE POSITIONING METHODS AT DISPOSAL SITES

Method	User Reported Accuracy (±m) Absolute	Repeatable	Restrictions
Visual sighting	300 and up	200-400	Visibility, landmarks
Radar ranges	200-300	200	Reflection resolution, I.D.; featureless shorelines; accuracy decreases with distance
Visuals, radar, depth	100-200	100	Same as above two
Variable range radar	100	30-50	Same as radar ranges, only better resolution

Operators often rely on visual sighting when possible, using standard or variable range radar only when visibility is impaired. Fathometer readings usually are taken if the disposal site is to be revisited. Some users take multiple VRR fixes regularly.

Although all tugs have Loran-C, operators agreed that it cannot be used in inland waters. It can be used to relocate a position with recorded Loran-C coordinates. Since relocation is not a standard coastal shipping navigation practice, few tug operators are familiar with this use of Loran-C.

At some disposal sites marked by buoys, operators position the barge near the buoy and then release the load. Accuracy during these operations is affected by offset between the buoy and its anchor chain and by distance between the buoy and the actual load release site. The long anchor chain required to compensate for tidal and wave displacement allows standard buoys to float long distances from their anchor position. Therefore, barges positioned near these buoys may not actually be within the dump zone.

Record keeping associated with barge positioning consists primarily of ship log entries, typically containing the origin, destination, and volume of the barge. Information on position fixes or site conditions is rarely recorded for subsequent users. The U.S. Army Corps of Engineers usually requires additional information from their contractors, including time of departure for and arrival at the disposal site. Barge operator scow sheets are used to maintain project yardage figures and record disposal amounts at each site.

CANDIDATE SYSTEM OVERVIEW

Methods other than those already used in Puget Sound for barge positioning are available. Characteristics, major advantages, and major disadvantages of each method listed below are summarized in this section. Detailed descriptions are presented in Appendix A.

- Multiple Horizontal Angles

  Theodolites
  Sextant Angle Resection

- Multiple Electronic Ranges

  Variable Range Radar
  Distance-Measuring Instruments (EDMI)
  Microwave Systems
  Loran-C
  Satellite Ranging

- Range and Angle

  Theodolite and EDMI
  Total Station
  Range-Azimuth Positioning Systems

- Physical Markers

  Range Boards
  Elastically Moored Buoys.

<u>Multiple Horizontal Angles</u>

Theodolites have the necessary angular accuracies at the anticipated maximum ranges. They are commonly used as surveying instruments and cost \$2,000 (30-second accuracy) to \$4,000 (10-second accuracy). At least two theodolites, two operators, a siting target on the vessel, and a three-way communications link to coordinate fixes are required (see Appendix A, Figure 1). Theodolites can be used only during daylight hours of good visibility.

Sextant angle resection techniques offer adequate angular accuracy ($\pm$10 seconds) and sextants cost \$1,000-\$5,000. A three-arm protractor

is required for plotting positions. Two operators should take simultaneous fixes on moving vessels. Because the operators are on board, a separate communication link is not necessary and they can also serve as crew. However, the method requires highly visible shore targets and is therefore useful only during daylight hours of good visibility. In addition, it is difficult for even an experienced operator to shoot an accurate fix from a moving platform in adverse weather.

Multiple Electronic Ranges

Positioning with multiple electronic VRR ranges provides adequate accuracies over anticipated distances. Equipment costs range from $4,000 to $10,000. Weather and visibility rarely limit use and extra personnel are not needed to help navigate.

Positioning with Electronic Distance-Measuring Instruments (EDMI) offers adequate accuracy but marginal range beyond 3 km (1.9 mi) without multiple prisms. EDMI systems cost $8,000-$15,000 apiece for long-range units and approach $40,000 for systems with prisms. EDMIs require two staffed stations, a three-way communications link to coordinate fixes, and multiple prism assemblies.

Several microwave navigation systems with sufficient accuracy and adequate range are available for $40,000-$90,000. These systems comprise two shore stations and an on-board transmitter. With an additional shore station, the hyperbolic mode can provide multiple user capability at any disposal site. Limitations include geometry of shore stations; vessel position in the coverage area (i.e., crossing angle limitations); and possible interferences from line-of-sight obstructions, sea-surface reflective nulls, and land-sea boundaries.

Positioning from Loran-C ranges offers acceptable repeatable accuracy for relocating at disposal sites. Receivers cost $1,000-$4,000 and do not require additional personnel. Limitations include interference in some areas of Puget Sound and the need to initially locate the site with another method.

Transit satellite-based methods currently do not offer sufficient accuracy except with multiple passes, which are impracticable when a dump site is only briefly occupied. In the future, required accuracies will be achievable using GPS satellite-based techniques ($10,000-$40,000 for first units; $1,000 for subsequent production models). Independent geosynchronous satellite networks, such as GEOSTAR, may become available at a system interrogator cost of $450 plus a monthly fee. This method is in the early planning stages and recently received FCC approval. Satellite methods do not require additional personnel.

Range and Angle

A theodolite and EDMI could be paired with a communication link for approximately $10,000-$12,000. Total stations developed for this purpose range in cost from $9,000 for a manual station to $15,000-$25,000 for a fully automated station. Optical and infrared range limitations exist, and the optical components can be operated only during dayight hours of good visibility. The range-azimuth navigational methods examined (see Appendix A) provide sufficient positional accuracy with a single station, and cost between $65,000 for manual tracking and $70,000-$100,000 for fully automated tracking.

Physical Markers

Two range boards set up on land are visually lined up by the vessel captain. Maintaining that bearing, the captain steers the ship toward the range boards. When the bands across them align, the vessel is within the dump zone. Depending on the distance between the disposal site and the range boards, this method may be more accurate than VRR fixes. As with other optical positioning methods, range boards can only be used during daylight hours of good visibility. Installation costs may therefore be difficult to justify.

Although not a positioning method per se, the placement of an elastically moored buoy at the center of a disposal site could help position barges within site boundaries. The elastic mooring confines the radius of the

buoy excursion from the anchor point (watch circle) to less than 10 percent of the water depth. The watch circle can be calculated by the manufacturer for the site conditions. A worst-case condition expected in Puget Sound of a 171-m (560-ft) depth and a 1.2-m/sec (4-ft/sec) current resulted in a watch circle radius of 40.7 m (133.5 ft) (Wyman, D., personal communication). The calculated watch circle radius was reduced to less than 7 percent of the water depth at a current speed of 0.6 m/sec (4 ft/sec). Even the larger barges would be within the dump zone if the load were released within 100 m (328 ft) of the buoy.

Elastically moored buoys cost approximately $11,000 each, including moorings. The major limitations of a buoy system are that each site must be surveyed to determine the location, depth, tidal height, and currents for the mooring design, and that the buoy must be accurately placed for proper operation. The elastic tethers of a similar buoy maintained by the U.S. Army Corps of Engineers New York District snap once or twice each year, usually after a barge runs over the buoy. Special repair equipment and upkeep may cost as much as $20,000 for each buoy per year (Tavolaro, J., personal communication). Buoys would be struck less often if barges were required to approach the site heading into the current (usually tidal in Puget Sound). This would increase barge maneuverability around the buoy without increasing the round-trip distance (Figure 3).

SITE RADIUS CRITERIA

Dump zone boundaries should be as small as practicable but large enough to accommodate maneuverability limitations of the barge and accuracy limitations of the positioning method. A circle of radius twice the length of the larger barges [i.e., length = 76 m (250 ft), radius = 152 m (500 ft)] is expected to provide sufficient positioning area under adverse weather. Positioning error due to accuracy limitations can be calculated for each method (see "Disposal Site Radius" discussion in Positioning Limitations chapter above). It is also possible to calculate the area available for barge positioning after the positioning error is subtracted from the specified radius of a dump zone. This "effective" radius available for barge positioning is shown for typical navigational accuracy levels and three possible site

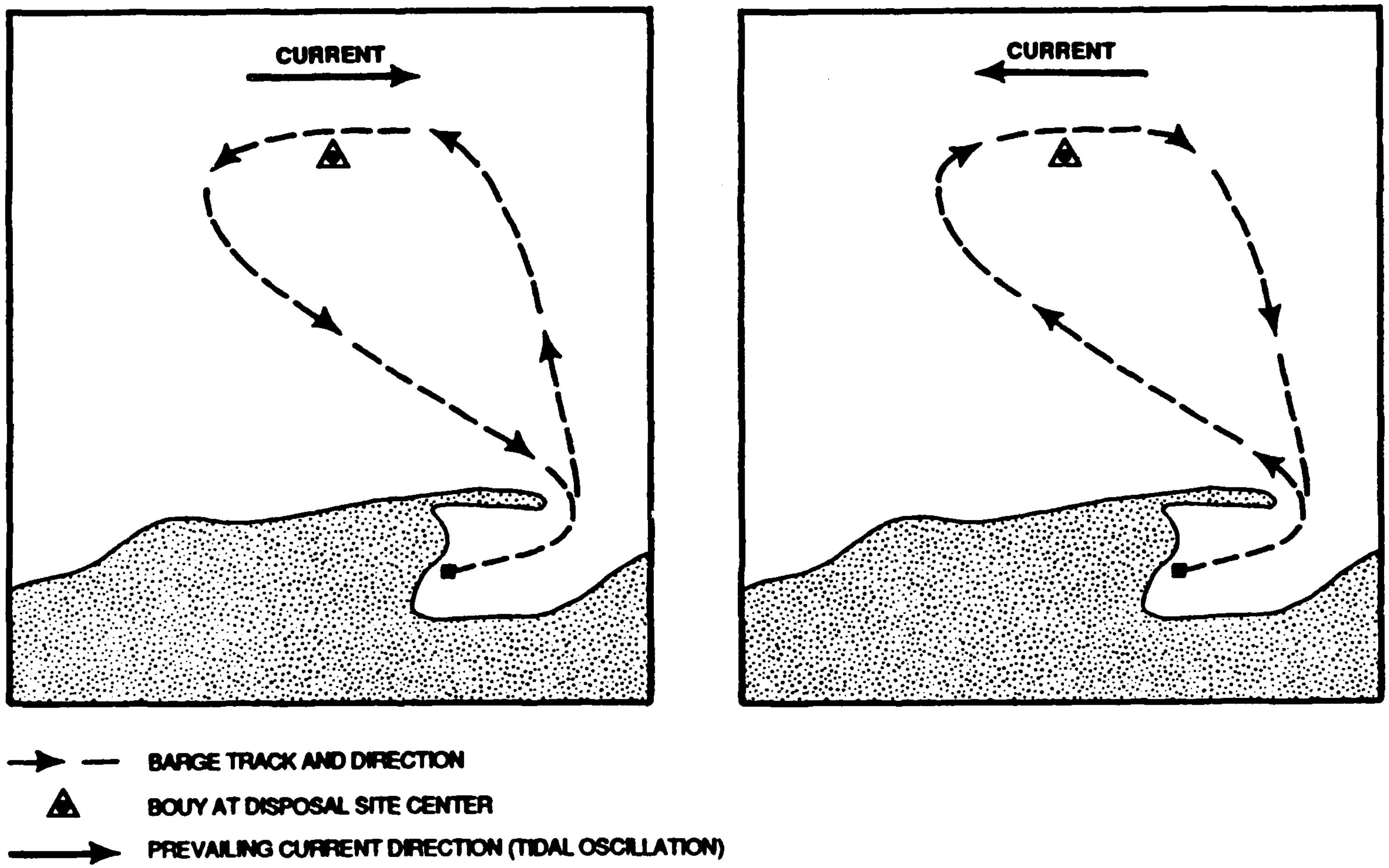

Figure 3. Barge track to disposal site buoy heading into the current.

radii in Table 2. The radii represent the range of sizes under discussion in Puget Sound. The probability level (P=0.68) is that associated with a radial error of 1 d_{rms}. A higher probability level would enlarge the barge's probable location area and further reduce the effective radius.

Two important points can be deduced from Table 2. First, a 91-m (300-ft) radius dump zone will not provide the positioning area needed for most barges [>40 m (131 ft) long], regardless of positioning method. Second, accuracies of ±200 m (±656 ft) and ±100 m (±328 ft) are not adequate for positioning within the existing 274-m (900-ft) radius dump zone. Using a method with an accuracy of ±100 m (±328 ft), an operator would have to position within a circle of less than one-half the radius of the 274-m (900-ft) dump zone [133 m (436 ft)] to ensure that the barge is within the disposal site. This area may accommodate the larger barges, but does not include a safety zone to compensate for drift during dumping [as much as 150 m (492 ft) in 10 min]. Using a method with a repeatable accuracy of ±20 m (±66 ft), an operator would be able to position within a circle of radius 246 m (807 ft), or three large barge lengths. Space not needed for maneuverability could be used to compensate for drift if a smaller area with a radius of approximately two large barge lengths were defined within the site in the coordinates or fixes of methods that have ±20 m (±66 ft) repeatable accuracy. Raising the navigational accuracy requirement from ±20 m (±66 ft) to ±2 m (±6.6 ft) would increase the effective radius by approximately 25 m (82 ft).

To allow for deterioration of accuracy under adverse conditions and to leave a reasonable area for positioning and drift, dump zone radii should not be less than 213 m (700 ft) for positioning methods with ±2 m (±6.6 ft) accuracy and 244 m (800 ft) for methods with ±20 m (±66 ft) accuracy. The present 274-m (900-ft) radius probably would be more appropriate in areas of higher current velocities to compensate for drift.

SCREENING CRITERIA

Candidate systems were evaluated for accuracy, flexibility (i.e., range of conditions under which the system can operate, including use for

TABLE 2. REDUCTION OF DISPOSAL SITE RADIUS BY POSITIONING ERROR

Positioning Accuracy (±m)[a]	Radial Error (m) (P=0.68)[b]	Effective Site Radius (m)[c]		
0	0	274	183	91
2	2.8	271	180	88
20	28	246	155	63
100	141	133	42	d
200	282	d	d	d

[a] Positioning error or accuracy capability inherent in method used.

[b] Calculated 1 d_{rms} at a 90 degree fix for a 68 percent probability that position is within a circle of this radius from the estimated position.

[c] Three different initial site radii are assumed: 274 m, 183 m, and 91 m. Numbers below each initial size represent the radius of the area available in the center of the dump zone within which a barge can position after accounting for error in estimate of position (column 2).

[d] Error in position is greater than size of dump zone.

other purposes), portability, reliability, servicing requirements, availability, cost, and convenience. Results of the evaluation are presented in Table 3. Methods are presented across the top of this table in order of increasing range capability. Methods eliminated from further consideration are marked by an asterisk. Limitations that precluded further consideration included inabilty to operate at night or in poor visibility (e.g., optical methods) or availability of comparable methods at lower cost with fewer logistical problems (e.g., medium-range systems). Remaining positioning methods (i.e., variable range radar, microwave, Loran-C, GEOSTAR, GPS, and elastically moored buoys) were reevaluated for range capability, accuracy, availability, capital and operating costs, and merits of use. This information is summarized below.

Range Capability

VRR, microwave, Loran-C, GEOSTAR, and GPS positioning methods have adequate ranges for use at disposal sites in Puget Sound. However, at sites farther from land, VRR must be used on higher range scales which are less accurate.

Accuracy

Based on the required accuracies to position within the site radii calculated in Table 2, VRR and Loran-C are practicable only with repeatable accuracy. Initial on-site definition of the dump zone in VRR and Loran-C coordinates is required. Microwave methods are marginal at sites with a radius less than 213 m (700 ft). The GPS satellite method accuracies, which vary with satellite code access, are between those of microwave systems and the repeatable accuracy of Loran-C and VRR. GEOSTAR is nearly as accurate as the microwave systems. The accuracy of buoy positioning depends upon the buoy excursion [a maximum of 40 m (131 ft)] from the center of the site and the distance between the buoy and the barge during dumping. Dump zone size based on accuracy of buoy positioning is not expected to be larger than that based on accuracy of satellite or microwave systems.

TABLE 3. EVALUATION OF NAVIGATION METHODS FOR BARGE POSITIONING AT DISPOSAL SITES

	Optical Methods	Variable Range Radar	Total Stations	Microwave Systems	Range-Asimuth Systems	Medium-Range Systems	Loran-C	GEOSTAR	GPS
Accuracy									
Absolute	H-L	L	H-M	H	H-M	H-M	M	H	H-M
Repeatable	H-M	M	H	H	H	M	M	H	H-M
Flexibility	L*	H	M-L*	H-M	M-L*	M-L	H-L	H	H
Portability	H-M	L	M	M	M	L	H	H-M	H-L
Reliability	H	H-M	H-M	H-M	H-M	H-M	H	?	M
Servicing									
Calibration	L	H	M-L	L	L	H-M	H-M	H	H
Maintenance	H	H	M	H	M	H-M	H	H	H
Availability									
Equipment	H	H	M	H	M-L	L*	H	?	M
Service	M-L	H	M-L	M	M-L	M-L	H-M	?	M
Rental	H	L	M-L	H	L	L	H	?	?
Cost	H	H-M	M-L	L	L*	L*	H	H-L	M-L
Convenience	L	H	L	L	L	L*	H	H	H-L

H = High ranking (adequate, above average, inexpensive, infrequent).

M = Medium ranking (marginal, average, intermediate).

L = Low ranking (not adequate, below average, expensive, frequent).

* = Significant enough limitation to preclude use as a positioning method.

? = Not enough information available to evaluate.

Availability

GPS does not yet have enough satellites in orbit to give consistent fixes without long time delays. GEOSTAR will not be operational for a few years. VRR, microwave, and Loran-C methods, and buoys are available.

Capital and Operating Costs

GPS capability is expected to cost from $10,000 to $40,000. Cost of later models is expected to drop to $1,000. Proposed GEOSTAR interrogators are expected to cost $450 plus a monthly use fee. VRR models range from $4,000 to $10,000. Loran-C units cost $1,000 to $4,000. Little or no operating cost is associated with these methods and the vessel captain can operate them. Microwave systems typically cost $40,000-$95,000, not including operating expenses. Microwave system rental would be less costly initially, but high site use would cause costs to accumulate quickly. Elastically moored buoys cost approximately $11,000 with annual maintenance costs as high as $20,000.

Merits of Use

Loran-C and VRR methods are sufficiently accurate only if operators are given a range of coordinates within which they must be positioned. The coordinates must be determined initially from on-site readouts in Loran-C or VRR by the regulatory agency. Considerable accuracy improvements would then be possible at minimal operator cost. Both Loran-C and VRR are routinely carried on board tugs, and one method may be used if the other is not working. Some operators will need to acquire a variable range marker for their radar. It may be possible to reduce dump zones to a 244-m (800-ft) radius with this method, but the existing 274-m (900-ft) radius is more realistic in areas with tidal currents above 51 cm/sec (1 kn).

By comparison, microwave methods offer increased accuracies [±2 m (±6.6 ft) vs. ±20 m (±66 ft)], but at a high cost. Logistical requirements of microwave positioning would disrupt normal operations, unless the appropriate regulatory agencies supervised shore station logistics and supplied on-board

equipment. The regulatory agencies would have to purchase numerous master units and store stations, and tug operators would need instruction in this method. The incremental reduction in dump zone radius compared to that of Loran-C or VRR is approximately 25 m (82 ft).

When available (approximately 1988), consistent satellite fixes are expected to offer the increased accuracies of microwave systems with the simplicity of Loran-C.

Prospective buoy sites require an initial survey and accurate placement at the design depth, but simplify positioning efforts. Positioning is expected to be as accurate as that using satellite or microwave methods. Tugs can use existing radar equipment to locate the buoy and to position within the dump zone. Sites with a bottom slope (e.g., Fourmile Rock) would not provide good anchorage and a released load could transport the buoy downslope. Maintenance may be costly and require special equipment.

MARGINAL COST OF INCREASED ACCURACY

Of the methods that meet the disposal requirements, only the microwave systems, buoys, and (in the future) satellite systems offer increased accuracies over Loran-C or VRR. Although the reduction from ±20-30 m (±66-99 ft) to ±2 m (±6.6 ft) in positioning capability gained from a microwave system does not affect tug/barge maneuverability limitations, it can result in a decrease of the dump zone radius by approximately 25 m (82 ft) to no less than 213 m (700 ft). The cost increase for microwave systems is a minimum of $30,000, plus operating costs of this labor-intensive method. Total incremental cost could reach $60,000 per operator. If the regulatory agency supplied the systems, it would cost a minimum of $30,000-$60,000 for each operational disposal site.

Dump zone size could effectively be reduced by placing buoys at sites with mild bottom slopes and heavy traffic use. The buoys may be moved to other sites by redesigning the mooring if site use declines. The high capital ($11,000) and operating costs ($20,000/yr) would be incurred for a small number of sites until satellite methods are available. The buoy

could then be used for other purposes. The long-term use of buoys appears to be the most expensive alternative to reducing the dump zone because of high operating costs.

Satellite positioning costs are difficult to estimate. Costs could range from marginal capital expenses and a small monthly rental fee to $30,000 per user, depending upon system developments and permit requirement deadlines. Until satellite methods are available and competitive, Loran-C and VRR accuracy levels could be accepted or microwave systems could be rented. The latter requires more time from barge operators.

SUMMARY AND RECOMMENDATIONS

Methods currently used in Puget Sound to position barges at disposal sites cannot consistently place the barge within dump zone boundaries. Alternative positioning methods were evaluated and rejected if their limitations were overly restrictive (e.g., inability to operate at night or in poor visibility; availability of similar, less expensive methods). The remaining methods were grouped into accuracy categories of $\pm$20-30 m ($\pm$66-99 ft) and $\pm$2 m ($\pm$6.6 ft). Variable range radar and Loran-C systems constitute the former category. Microwave and satellite systems constitute the latter category.

Dump zone boundaries should be established by determining an area adequate to position larger barges, and then enlarging the area to compensate for positioning error and drift. A small circle within the site should be designated as the actual zone for users. Coordinates of the area should be determined on site by the method that will be required of users. The minimum radius required for barge positioning appears to be 120-180 m (394-590 ft), not including area for drift and positioning error. If positioning methods with an accuracy of $\pm$20 m ($\pm$66 ft) are selected, a 244-m (800-ft) site radius should be adequate to compensate for positioning error and drift. In areas of stronger currents (exceeding 1 kn with the tide) a 274-m (900-ft) radius would be more appropriate. If positioning methods with an accuracy of $\pm$ 2 m ($\pm$6.6 ft) are selected, a 213-m (700-ft) radius

should be adequate for most locations. In areas of higher tidal currents, an expansion of the radius by 31 m (100 ft) would be more appropriate.

Positioning by an elastically moored buoy will be as accurate as methods with $\pm$2-m ($\pm$6.6-ft) accuracy [213 m (700 ft)] when buoy excursion, barge length, proximity to the buoy, and drift are considered. Experience may prove that the disposal area actually used is smaller than that achieveable using $\pm$2-m ($\pm$6.6-ft) accuracy methods.

Loran-C and VRR are the easiest to implement, have the lowest cost, and require equipment common on most tugs in Puget Sound. However, use of Loran-C and VRR requires a set of coordinates for the actual user disposal zone determined by the regulatory agency during surveys that compare Loran-C and VRR fixes with those of a higher accuracy method. Coordinates for both Loran-C and VRR methods should be defined so that either may be used if problems or interferences develop.

Microwave systems provide the increased accuracies of a $\pm$2-m ($\pm$6.6-ft) method and reduce the dump zone, but at a high cost. Additional problems with shore station security, logistics, and training increase the requirements of the regulatory agencies and further consideration of these systems is not recommended.

Satellite positioning methods will be usable within a few years and offer accuracies comparable to those of microwave methods with the simplicity of Loran-C. The relative cost of satellite positioning over Loran-C and VRR should decrease rapidly. Satellite positioning is expected to become the standard navigation method in the near future.

Placement of elastically moored buoys at disposal sites would require only standard radar equipment for positioning. Dump zone size reductions would be comparable to those of microwave or satellite systems. Buoys could be particularly useful in reducing the depositional area of disposal sites with stronger currents or greater depths [>122 m (400 ft)]. The high capital and operating costs associated with buoys (especially at multiple sites) is a major limitation.

Site characteristics that could affect barge positioning are summarized in Table 4 for each of the existing and considered disposal sites in Puget Sound. These limitations are addressed in the following alternative recommendations:

1. **Use both Loran-C and VRR at all sites.** This will require the regulatory agency to determine positioning coordinates for each site. An organization otherwise conducting studies in the area with a microwave system could relatively easily determine corresponding Loran-C and VRR coordinate ranges to define the user boundaries. The use of both Loran-C and VRR systems provides redundancy and allows VRR fixes to be used at sites with Loran-C interference. Boundaries may be reduced to a 244-m (800-ft) radius at sites with low currents and either Loran-C coverage or adequate proximity to shore for accurate VRR fixes (Sites 2, 5, and 7 of Table 4). A 244-m (800-ft) radius is also acceptable at deeper sites with low currents to restrict the depositional area (Sites 4 and 6). Boundaries should be kept at 274 m (900 ft) at sites with strong currents, at sites not covered by Loran-C with long ranges for VRR fixes, and at sites that can have severe wind and wave conditions (Sites 1, 3, 8, 9, 10, 11, 12, and 13).

2. **Use Loran-C and VRR until GEOSTAR or GPS satellite systems become cost-effective.** Satellite systems will allow reduction of the disposal boundary radii suggested in alternative #1, above, by 31 m (100 ft). They can be used at any site and will be as easy to operate as Loran-C. Satellite positioning methods are expected to become the common method of navigation, and costs are expected to decrease. Until that time, Loran-C and VRR should be used as specified in Alternative #1.

TABLE 4. DISPOSAL SITE CHARACTERISTICS THAT AFFECT BARGE POSITIONING

	Disposal Sites[a]	Currents[b]	Rough Conditions[c]	Deep Sites[d]	Loran-C Interference	Longer Ranges[e]	Bottom Slope
1.	Admiralty Inlet	X	X	X	X	X	
2.	Bellingham Bay						
3.	Bellingham Channel	X	(X)		(X)	(X)	
4.	Commencement Bay		(X)	X			
5.	Inner Elliott Bay						
6.	Fourmile Rock		(X)	X			X
7.	Padilla Bay				X		
8.	Port Angeles	X	X			X	
9.	Port Gardner		(X)	X	X	X	
10.	Saratoga Passage		X	X	X		
11.	Skagit Bay	X			X		
12.	Steilacoom	X	(X)	X		(X)	(X)
13.	Twin Rivers	X	X	X		X	

[a] Existing sites and sites under consideration.

[b] Tidal and mean currents that exceed 51 cm/sec (1 kn).

[c] Wind or wave condition that could affect maneuverability, drift.

[d] Sites deeper than 122 m (400 ft).

[e] Distance from shore (and targets) that will reduce VRR accuracy.

(X) Less likely to be of influence.

3. **Use elastically moored buoys at appropriate sites and Loran-C and VRR at remaining sites until satellite systems become cost-effective.** Until satellite systems are more practicable, elastically moored buoys can be used for positioning where it is especially important to restrict depositional area. These might include high-use sites, deeper sites (Sites 1, 4, 6, 9, 10, 12, and 13), or ones with high tidal currents causing large drift (Sites 1, 3, 8, 11, 12, and 13). At less frequently used sites, Loran-C and VRR could be used to reduce the number of buoys and the associated costs.

MONITORING METHODS

Methods to monitor disposal operations at Puget Sound disposal sites are addressed in this chapter. Monitoring methods are evaluated to eliminate those that do not meet monitoring capabilities identified by agencies responsible for disposal site management. Remaining methods are screened for their ability to meet specific criteria, and alternative recommendations for methods of monitoring Puget Sound disposal sites are provided. Monitoring methods and associated equipment are described in detail in Appendix A.

MONITORING PROCEDURES IN USE IN PUGET SOUND

Disposal site monitoring was tested at the Fourmile Rock site in Puget Sound by the Washington Department of Natural Resources (WDNR). The U.S. Coast Guard Vessel Traffic Service (VTS) Radar was used to verify that barges were within the disposal boundary before loads were released. VTS was used successfully to position the barge within site boundaries and to monitor the time and location of the reported waste release. The VTS Radar range accuracy was 37 m (121 ft) at the Fourmile Rock site. Specific characteristics of the VTS system are presented in Appendix A.

Test procedures required the tug operator to call over the Coast Guard traffic channel and request verification that the barge was within the 274-m (900-ft) radius dump zone boundary. If the barge was not within the boundary, the Coast Guard would inform the operator of the bearing and distance to the site center, and the process would be repeated. Initially, the requirement to center the barge within the disposal site delayed disposal operations up to 2 h because the tug/barge had difficulty changing direction in short distances. When the acceptable position area was expanded by WDNR to include the entire site, significant delays were avoided. Because tugboat operators must otherwise notify VTS when entering or leaving vessel traffic lanes, VTS monitoring requirements did not affect normal operations and were acceptable to most operators.

Limiting factors of VTS monitoring include inability to independently verify the time of the load release (i.e., whether disposal occurred within site boundaries) and incomplete coverage of Puget Sound. Release within the dump zone was assumed if position within the dump zone was verified. If tug operators were required to notify VTS when ready to release the load and when ready to depart (i.e., after completing a release), time and position data could be used to confirm compliance with dump zone boundaries and to evaluate drift problems. Only four existing Puget Sound disposal sites are within VTS coverage (Figure 4). Because VTS serves as a positioning method, additional positioning requirements are not needed at VTS sites and tug operators can use normal means of navigation to approach them. Alternate positioning and monitoring methods are needed for remaining sites.

CANDIDATE SYSTEM OVERVIEW

Monitoring methods fall into three principal categories:

- User record methods
- Shore-based observer methods
- Remote electronic methods.

These methods and their characteristics are presented below.

User Record Methods

Disposal permits could be written to require detailed user records of each disposal operation. Logs containing coordinates and times of each of the following events could be used to verify proper barge position during load release: arrival on site, opening of doors, initiation of release, and closing of doors. Costs to the user would be minimal. Costs to the funding agency also would be minimal, except that each site must be defined by the regulatory agency in coordinates based on appropriate navigation methods. Site use could be documented by requiring regular submittal of log data to the regulatory agency. Entry of false data would be punishable

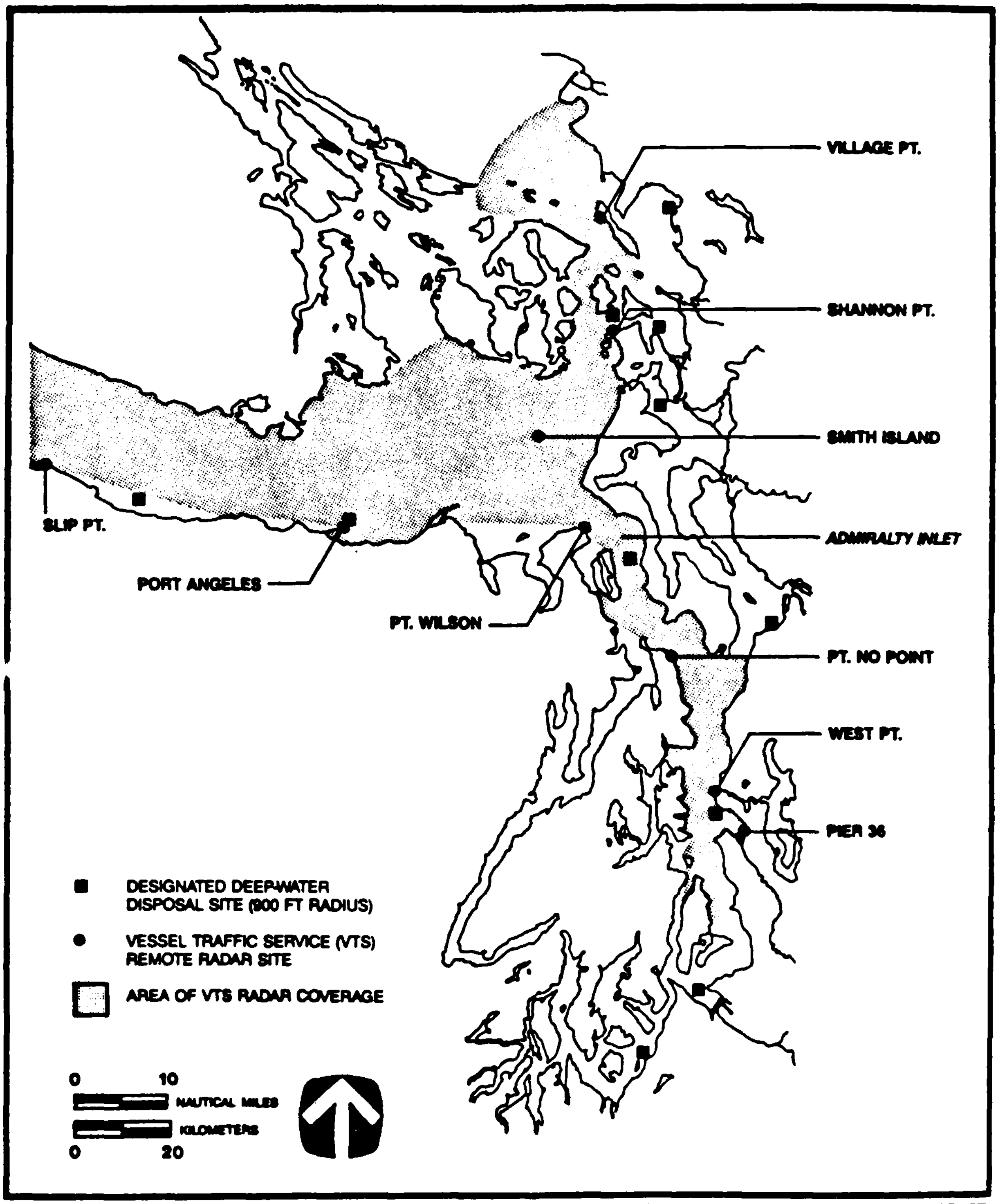

Figure 4. Comparison of existing disposal site locations to the areas of Vessel Traffic Service radar coverage.

by fine and loss of disposal permit. Spot checks to discourage infractions and document falsification would strengthen this approach as a monitoring method. Limitations include the inability to verify the time of release and the possible difficulty of using records as legal evidence.

Shore-Based Observer Methods

Methods for shore-based observation include rangefinder photography, total stations, and range-azimuth systems. While the barge is on site, remote rangefinder photographs are triggered by a crew member or by an attendant on land. Because accuracy is insufficient to verify boundary compliance and because use is limited to daylight hours of good visibility, this method is not considered further.

Total stations and range-azimuth systems were discussed under "Range and Angle" in the Candidate System Overview section of the previous chapter. Initial costs range from $9,000 to $100,000, excluding survey expenses for one monitoring station for each disposal site (if existing monumented points are inadequate) and for observer costs. Systems are portable and only one station and observer are required. Limitations include the inability to verify the time of release (unless a distinct barge jump is noted) and the inability to operate except during daylight hours of good visibility without automatic tracking systems.

Remote Electronic Methods

The VTS Radar method can accurately verify position within site boundaries for sites within its coverage area. Operating procedures to simplify barge approach and position verification are needed to reduce maneuverability problems. Costs would be minimal to the funding agency and the users. Load release locations and times could be verified by the operator only. Notification at the end of the release would provide additional position monitoring information. Documentation must be provided by the U.S. Coast Guard.

The remaining remote electronic methods [i.e., ODSS (Ocean Dumping Surveillance System), Pathlink, Vehicle Tracking System, CORT 5000, and TRACKER] are based upon Loran-C navigation. Periodic Loran signal interference is a problem at several existing disposal sites (Figure 5). Positioning data are unreliable during signal interference and monitoring may provide erroneous information on vessel locations. Loran-C-based methods can be modified to accept GPS or GEOSTAR positioning data when the satellite information becomes widely available. Conversion to a satellite-based method will minimize signal interference problems, eliminate coverage restrictions, and improve position monitoring accuracy. The advantages of these methods include portable on-board remotes, centralized (real-time) monitoring, multiple vessel capability, absence of remote shore-based stations, and data storage for later analysis.

Dedicated remote monitoring methods record location and time, and track the path of the barge. Most can detect the release time. ODSS (the U.S. Coast Guard "Black Box" system) offers some data storage in the remote unit if telecommunication fails. The price is approximately $10,000 per remote unit, with variable central base unit costs. The Pathlink system is easily operated and offers an additional remote storage capability with a permanent record if power fails. The system costs $30,000-$40,000. The Vehicle Tracking System unit offers less remote storage capability and costs $25,000-$35,000. The CORT 500, with remote storage, costs about $11,000 per remote unit plus base unit expenses. The TRACKER, with no data storage (i.e., loss of record if the radio link is lost--a distinct possibility at times in Puget Sound), costs at least $30,000.

SCREENING CRITERIA

Monitoring methods were evaluated for accuracy, flexibility, portability, reliability, serving requirements, availability, documentability, cost, convenience, and required user knowledge. Results are listed in Table 5. Severe limitations that eliminated methods from further consideration included the inability to monitor in restricted visibility and complex logistical requirements. Rejected methods could, however, be used to spot-check disposal operations and crosscheck records.

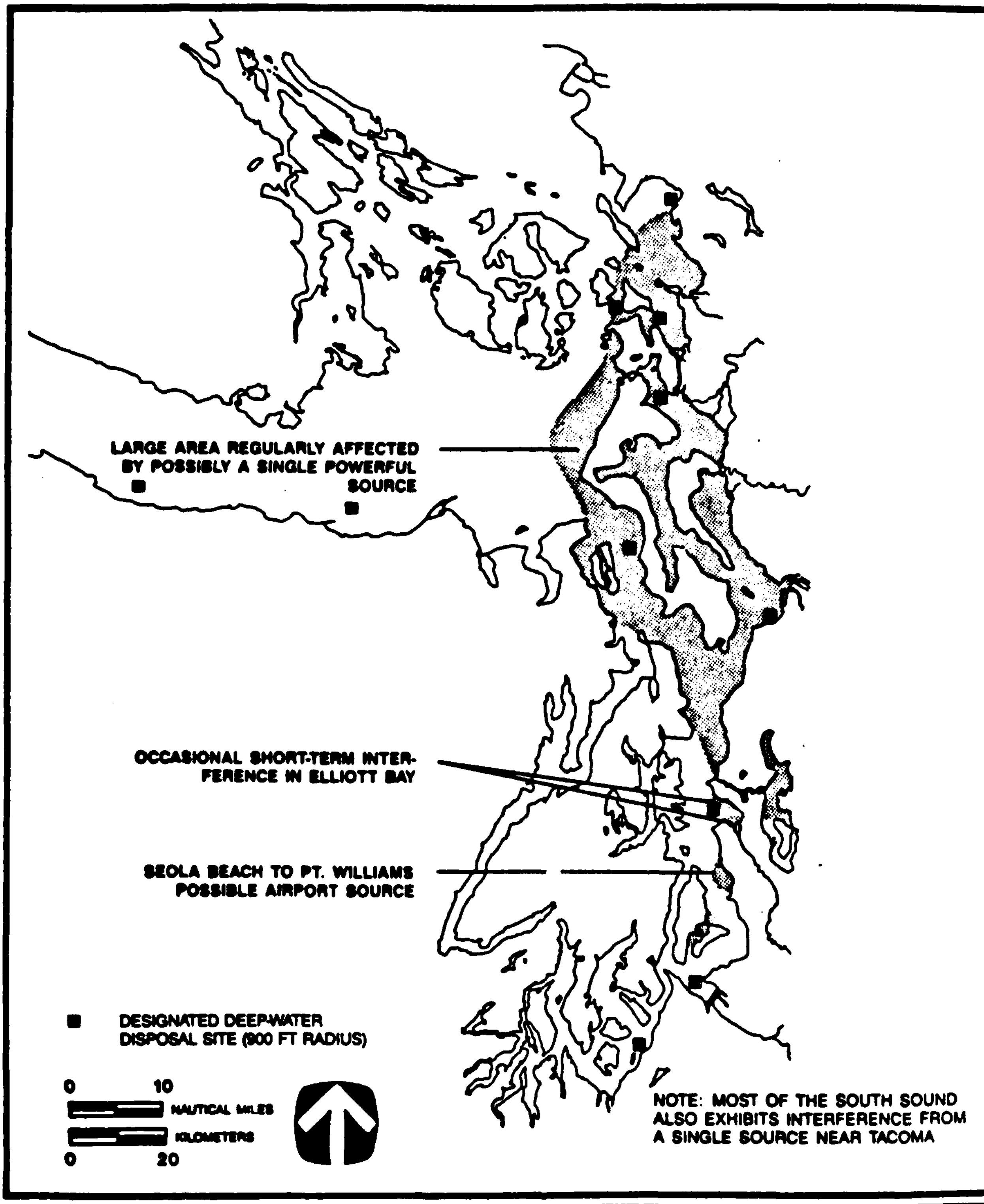

Figure 5. Existing disposal site locations in relation to regions of LORAN-C signal interference.

TABLE 5. EVALUATION OF METHODS FOR DISPOSAL SITE USE MONITORING

	Detailed Site Use Log Requirements	Total Stations	Range-Azimuth Systems	ODSS	Pathlink	Vehicle Tracking System	CORT 500	TRACKER	VTS Radar
Accuracy									
Absolute	M	H-M	H-M	M	M	M	M	M	M
Repeatable	M	H	H	M	M	M	M	M	M
Flexibility	H	L*	M-L*	H-M	H-M	H-M	H-M	H-M	M-L
Portability	H	M	M	H-M	H-M	H-M	H-M	H-M	H
Reliability	H-L	H-M	H-M	M	H	M	M	M	H
Servicing									
Calibration	H	L	L	H-M	H-M	H-M	H-M	H-M	H
Maintenance	H	M	M	H-M	H-M	H-M	H-M	H-M	H
Availability									
Equipment	H	M	M-L	M-L	M-L	M-L	M-L	M-L	H
Service	H	M-L	M-L	M	M	M	M	M	H
Rental	H	M-L	L	L	L	L	L	L	H
Cost	H	H-M	L*	M-L	M	M	L	L	H
Convenience	H	M-L*	M-L*	H	H	H	H	H	H-M
User Sophistication	H	M-L	M-L	M	H-M	H	H	M-L	H
Documentability	H-L	M-L	M-L	H	H	H	H	H	H-M

H = High ranking (adequate, above average, inexpensive, infrequent).

M = Medium ranking (marginal, average, intermediate).

L = Low ranking (not adequate, below average, expensive, frequent).

* = Significant enough limitation to preclude use as a monitoring method.

Remaining methods were reevaluated for range capability, accuracy, availability, cost, and merit. The information is summarized below.

Range Capability

The remote monitoring and user record methods are independent of range considerations. The VTS Radar method is applicable only for sites within the existing coverage area. Extension of coverage to Commencement Bay has been planned but not budgeted. Disposal sites outside the range of coverage must be monitored with another method.

Accuracy

The user record method is independent of accuracy considerations. Accuracy of remote electronic systems is adequate to verify site use compliance. Accuracy of satellite-based systems is approximately one order of magnitude greater than that of Loran-C-based systems. Bearing and range accuracy of the VTS Radar system is sufficient to define barge positions, even at the highest range scale operated in Puget Sound, with greater accuracy at low range scales. If disposal boundaries are so reduced that VRR and Loran-C cannot be used as positioning methods, then Loran-C remote systems, and possibly VTS, would be ineffective as monitoring methods.

Availability

The VTS Radar system is available for monitoring use and the U.S. Coast Guard has indicated that it will provide adequate reporting to the regulatory agency. Most remote monitoring systems are built to user specifications. Switchover to satellite receiving must be verified by the individual companies. Availability of equipment for future conversion is not known.

Capital and Operating Costs

The user record-keeping approach and VTS Radar monitoring involve costs for set-up and ongoing review of monitoring data. The remote systems

cost $25,000-$40,000 (Pathlink, TRACKER, Vehicle Tracking System) or $10,000 per remote unit plus base station costs (ODSS and CORT 500), not including base station operational expenses. For most systems, a single operator is sufficient. Additional costs for start-up and programming depend upon the method. Manufacturer cost estimates require detailed description of user needs.

Merits of Use

These monitoring methods require little operator effort. The ODSS and Pathlink remote systems require mounting of pressure transducers on the barges for hookup to the remote system when it is taken on board. Pressure transducers will verify the load release time and location. Other remote systems may also be capable of handling transducers. Remote systems without pressure sensors cannot directly verify dump time. But because there is no advantage of releasing a load outside dump zone boundaries if position within the boundaries must be verified in any case, tranducers are not necessary. Although remote methods are costly, they may have other applications (e.g., tracking hazardous waste containers). Satellite positioning would remove the interference and location restrictions of Loran-C. Satellite capability must be verified by the manufacturer.

The VTS Radar monitoring system is in place and requires minimal agency involvement. However, VTS Radar cannot be used to directly verify dump time and does not cover all disposal sites. Thus, shore-based observations or site user records would be necessary. Shore-based methods require placement of prisms or transponders on the barges (total stations and range-azimuth systems) or simultaneous fixes from two observers (theodolites). Use of theodolites is limited to periods of good visibility.

The user record-keeping approach requires a deterrent to false entries (e.g., fines for falsifying logs and random spot checks). Spot-checking would reduce agency monitoring expenses, although occasional equipment rentals would be necessary. Adequate documentation helps the regulatory agency identify use trends, understand site-specific problems, including

drift at sites with high currents, and improve the database for subsequent impact evaluations.

SUMMARY AND RECOMMENDATIONS

Monitoring methods were evaluated to determine potential use at Puget Sound disposal sites. Methods not considered appropriate include those with severe visibility limitations and those with high logistical requirements. The remaining methods require little operator effort. Site use records and VTS Radar monitoring would be the easiest programs to implement. Remote monitoring methods would be more expensive and labor-intensive.

Compliance with site boundaries can be monitored by requiring users to record specific times and locations of significant disposal events. Although the location of load release can only be inferred from the records, the regulatory agency can determine whether the barge was positioned within the dump zone. Disposal within the dump zone would be assumed if position in the zone was verified. The records are also useful for site management and subsequent environmental monitoring. Fines for falsifying records and random spot checks by shore-based observers would encourage compliance.

The existing U.S. Coast Guard VTS Radar method can be used to both position and monitor barges in some areas of Puget Sound (see Figure 5). Actual time of dumping can be verified only by requiring VTS notification at the start and end of each dump.

The remote monitoring methods record information and send it to a central base unit. A small box must be placed on the barge to monitor time and position. The Loran-C-based systems are subject to intermittent interference in parts of Puget Sound. If these missing records are required, or if sites have persistent interference problems, alternative monitoring methods must be used. Most of these systems can be modified for satellite positioning when it is more easily available.

Remote systems are designed for specific management needs. Determination of the system best suited for PSSDA's purpose is beyond the scope of this

document. Specific requirements for inputs, outputs, data storage and manipulation, and the number of expected remote units must be established before designing a suitable system. Additional information on system service and start-up should be solicited from manufacturers and future modifications for satellite input should be considered.

Site characteristics that could affect position monitoring are summarized in Table 6 for each of the existing and proposed disposal sites in Puget Sound. These limitations are addressed in the following alternative recommendations:

1. **Require operator record keeping at all sites and spot-check with shore-based operations.** This requires the regulatory agency to determine the positioning coordinates and fixes for each site. The coordinates reported by the user can be compared with those of the dump zone to determine whether the barge was within the boundaries at the start and end of the dumping operation. Shore-based observations with theodolites (two operators and communication) or total stations and range-azimuth systems (one operator) would be needed to perform random spot checks to discourage noncompliance. Optical resolution (theodolites and some total stations) may be a limiting factor for Sites 1, 3, 8, 9, 12, and 13 in Table 6. Single-station methods logistically are simpler to use and have fewer visibility restrictions, but will require multiple prism assemblies on disposal barges. The regulatory agency will have to purchase enough prisms for site traffic loads (the shore stations can be rented during periods of spot-checking). Presence of the prisms on the barges may encourage more careful and honest record keeping.

2. **Use VTS Radar coverage where available and supplement with spot-checking at other sites.** The regulatory agency will have to coordinate with the U.S. Coast Guard on positioning procedure and documentation. Position fixes at the start and the end of the dump should be required. Only Sites

TABLE 6. DISPOSAL SITE CHARACTERISTICS THAT AFFECT BARGE POSITIONING MONITORING

	Disposal Sites[a]	VTS Coverage	Loran-C Reception[b]	Longer Ranges[c]
1.	Admiralty Inlet	X		X
2.	Bellingham Bay		X	
3.	Bellingham Channel	X		(X)
4.	Commencement Bay		X	
5.	Inner Elliott Bay	X	X	
6.	Fourmile Rock	X	X	
7.	Padilla Bay			
8.	Port Angeles	X	X	(X)
9.	Port Gardner			X
10.	Saratoga Passage			
11.	Skagit Bay			
12.	Steilacoom		X	(X)
13.	Twin Rivers		X	X

a Existing sites and sites under consideration.

b Sites not included experience sporadic or persistent interference, although positioning data can be collected during periods of good reception.

c Distance from shore may affect optical monitoring methods.

(X) Less likely to be of influence.

1, 3, 5, 6, and 8 (Table 6) can be monitored by VTS Radar. VTS Radar can be used at these sites for positioning and the regulatory agency will not need to determine the positioning coordinates. The remaining sites must be monitored by the procedure noted in Alternative #1. The same records should be required from all sites, except that dump coordinates will be provided by the U.S. Coast Guard for VTS-covered sites.

3. **Use a remote monitoring system and supplement with spot checks.** This alternative will require the agency to determine positioning coordinates and fixes for each site. Sites 2, 7, 9, 10, and 11 experience sporadic or persistent interference of the Loran-C signals. Such problems should be eliminated by switching to satellite signals when they become available. The system appropriate to PSDDA needs will have to be determined. Placement of the box on the barge and the part-time monitoring at sites 2, 7, 9, 10, and 11 might be adequate to produce consistent compliance; otherwise these sites must be spot-checked using procedures in Alternative #1. The same records noted in alternative #1 should be required for all sites.

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APPENDIX A
POSITIONING AND POSITION MONITORING METHODS AND CHARACTERISTICS FOR DREDGE MATERIAL DISPOSAL IN PUGET SOUND

The various navigational positioning techniques are listed in Table 1. This detailed information provides quick-reference review of the performance characteristics and costs of methods representative of each class. These methods are grouped by maximum range to facilitate comparison to disposal sites within Puget Sound. Optical methods are presented first, followed by electronic methods.

OPTICAL POSITIONING TECHNIQUES

Methods Available

The traditional optical positioning method involves observations of two horizontal sextant angles between three fixed shore targets, plotted as a graphical resection using a three-arm protractor or station pointer. Other optical positioning methods are available (Table 1), but only this and the theodolite intersection method are practical in more open waters [150 m (492 ft) to 5 km (3.1 mi) from shore]. Because the remaining optical methods cited apply only to river or harbor surveys, at extremely short ranges, or in very calm water, they are not useful over the range of expected disposal site locations in Puget Sound and are not discussed further.

Theodolite Intersection

Position of the disposal barge or towing vessel can be established by two onshore observers who simultaneously measure the angle between a reference object or shore traverse and the vessel (Figure 1). A rod or other aiming point normally is erected on the vessel. Radios, flags, or lights signal the moment at which angle measurements should be made. A theodolite with an accuracy of ±15 seconds for single angle measurement,

TABLE 1. SUMMARY OF VESSEL POSITIONING METHODS

Close Range-Direct [up to 5 km (3.1 mi)]

- Horizontal Sextant Angle Resection
- Theodolite Intersection from Shore
- Subtense Ranging by Vertical Angle
- Intersecting Ranges
- Range Line and Angle from Shore or Vessel
- Angles from Shore and Vessel
- Angles and Stadia or Distance from Shore
- Range Line and Uniform Speed
- Distance Line Ranging

Close Range-Indirect [up to 5 km (3.1 mi)]

- Laser
- Infrared Electromagnetic Distance

Short Range [up to 40 km (25 mi)]

- Variable Range Radar
- Microwave Electronic Positioning (300 MHz-300 GHz)

Medium Range [100-300 km (62-186 mi)]

- Medium and High Frequency Electronic Positioning (300 KHz-300 MHz)

Long Range [to 2000 km (1243 mi)]

- Low Frequency Electronic Positioning (30-300 KHz)

Global Positioning

- Very Low Frequency, Satellite, Astronomical Observations (3-30 KHz)

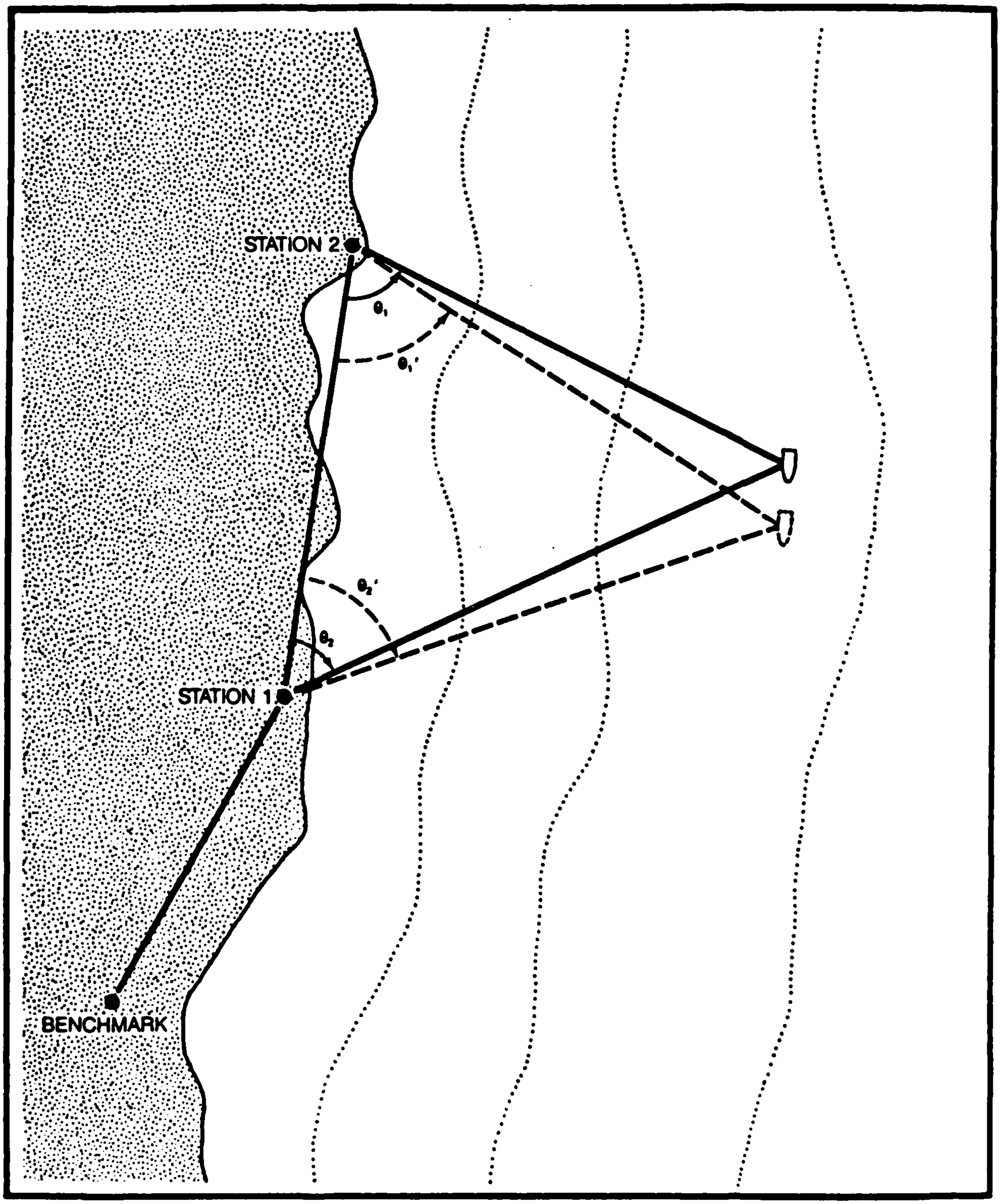


Figure 1. Station positioning by theodolite intersection.

intercept angles near 45°, and a range of 5 km (3.1 mi), should yield a position error less than ±1 m (3.3 ft) (Ingham 1975). Characteristics of theodolites used for such measurements are summarized in Tables 2 and 3.

Although the accuracy of this method appears high, its use in open waters has several distinct disadvantages. Complex arrangements usually are needed to ensure that angles are measured by two onshore observers at the same instant of the desired fix. This is not a problem when the vessel remains on station for a long period of time. Lines from the two theodolites should intersect at nearly right angles. As indicated in the error analysis discussion, weak position fixes or corresponding large positional areas of uncertainty result when the angles measured are less than 30° or more than 150°. Each of the onshore observer stations must be surveyed to maintain accuracy. Finally, as with all optical methods, target movement and path interferences (e.g., fog, heavy rain, or heat waves) can confound the measurements. In spite of these disadvantages, the procedure offers relatively high accuracies at low capital cost (although labor costs can rapidly add up) and has been successfully applied during favorable weather. It also is advantageous as a monitoring method, although observers may not be able to discern whether the actual dumping occurred unless a distinct barge jump is noted. It is therefore considered a candidate method for a monitoring program or barge positioning.

Sextant Angle Resection

An offshore position can be fixed by measuring the two horizontal angles between lines-of-sight to three identifiable targets with known positions. When a vessel is underway, the sextant angles must be measured simultaneously by two observers. The measurement of the first angle between the center and one outside target allows determination of a circle of position (COP) on which the sampling vessel must lie (Figure 2). For example, when the measured angle is 52°, the first circle of position is plotted by subtracting this angle from 90° and drawing lines seaward from the siting targets at the resultant angle of 38° from the baseline. These lines cross at the center of the COP, which can then be drawn with a compass. This procedure is repeated using the center and remaining targets, resulting

TABLE 2. SUMMARY OF VERNIER TRANSIT AND SCALE-READING THEODOLITE CHARACTERISTICS

COMPANY	MODEL	VERNIER MICROMETER OR SCALE DIVISION	POSSIBLE ESTIMATION	U.S. SUGGESTED LIST PRICE*
Benchmark	JENA 020	20"	10"	$2495
Berger	Bronze 65/45	20"/1'	20"/30"	$2125/3850
	Aston 67	20"	20"	$1835
	Project 100	1'	30"	$1100
	ST-1/6	1'/20"	30"/20"	$699/1499
	ST-8/9	20"	10"	$1699/1899
Kern	K1-S/ST	30"	6"	$3895/3995
Leitz	BT20/10C	20"	10"	$1695/1995
	115	1'	30"	$795
	TS20A/S6	1'	20"/6"	$2495/3695
Nikon	NT-2S MK III	1'	0.2'	$3195
	Schneider 700/400	20"/1'	6"/20"	$1235/650
Pentax	GT-4B/6B	20"		$1695/1895
	TH-60S/60E	1'	6"	$2500/1895
Teledyne	OP 107/100-A-20	20"	20"	$1295/1185
	6-15	20"	20"	$1350
	400W	1'		$650
Topcon	AG-30B	30"	15"	$1595
	TL-60SE	1'	20"	$2100
Warren-Knight	10-2220/3200	20"/1'	10"/30"	$2695/1295
White	TR-300	1'		$749
	TR-303/303PM	20"		$1879/1995
	T-307AT/309T	1'/20"	6"/10"	$2695/2350
Wild	T-16		12"	$1895
	T-05	20"	10"	$3950
Zeiss	Th-42/43	20"	10"	$3950

*January 1985

TABLE 3. SUMMARY OF MICROMETER AND DIGITIZED THEODOLITE CHARACTERISTICS

COMPANY	MODEL	VERNIER MICROMETER OR SCALE DIVISION	POSSIBLE ESTIMATION	U.S. SUGGESTED LIST PRICE*
Benchmark	JENA 010A	1"	0.1"	$4295
	JENA 015B	6"	1"	$3495
Kern	DKM2-A/T	1"	0.1"	$5890
	DKM3/DKM3-A	0.5"	0.1"	$12295
Lietz	DT-20E	20" Accuracy	10" Display	$2995
	TM6/10E/20H	6"/10"/20"	2"/5"/10"	$3995/3695/3295
	TM-1A	1"	0.1"	$5995
Nikon	NT-1/5A	20"/1"	6"/0.25"	$1895/5950
	NT-40/30/20	6"/10"/20"	1"/2"/4"	$3695/3595/3095
Pentax	TH-20D/10D/06D	20"/10"/6"	5"/2"/1"	$2850/3500/3690
	TH-01W	1"	0.5"	$4900
David White	TH 10-20/10	20"/10"	2"/1"	$2850/3500
	T-30BAT/20BAT	20"/10"	10"/5"	$2995/3495
	TH 10-1	1"	0.1"	$5500
Topcon	DT-20	LCD Readout 20"	-	$2695
	TL-20DE/10DE/6DE	20"/10"/6"	10"/5"/3"	$2859/3500/3690
Wild	T-0/T-1	20"/6"	20"/3"	$3995
	T-2/T-3	1"/0.2"	0.1"/0.1"	$5995/11995
	T-2000	0.5"	0.1"	$13995
Zeiss	Th-2	1"	-	$5950
	1Th-2	0.6"	-	$16500

*January 1985

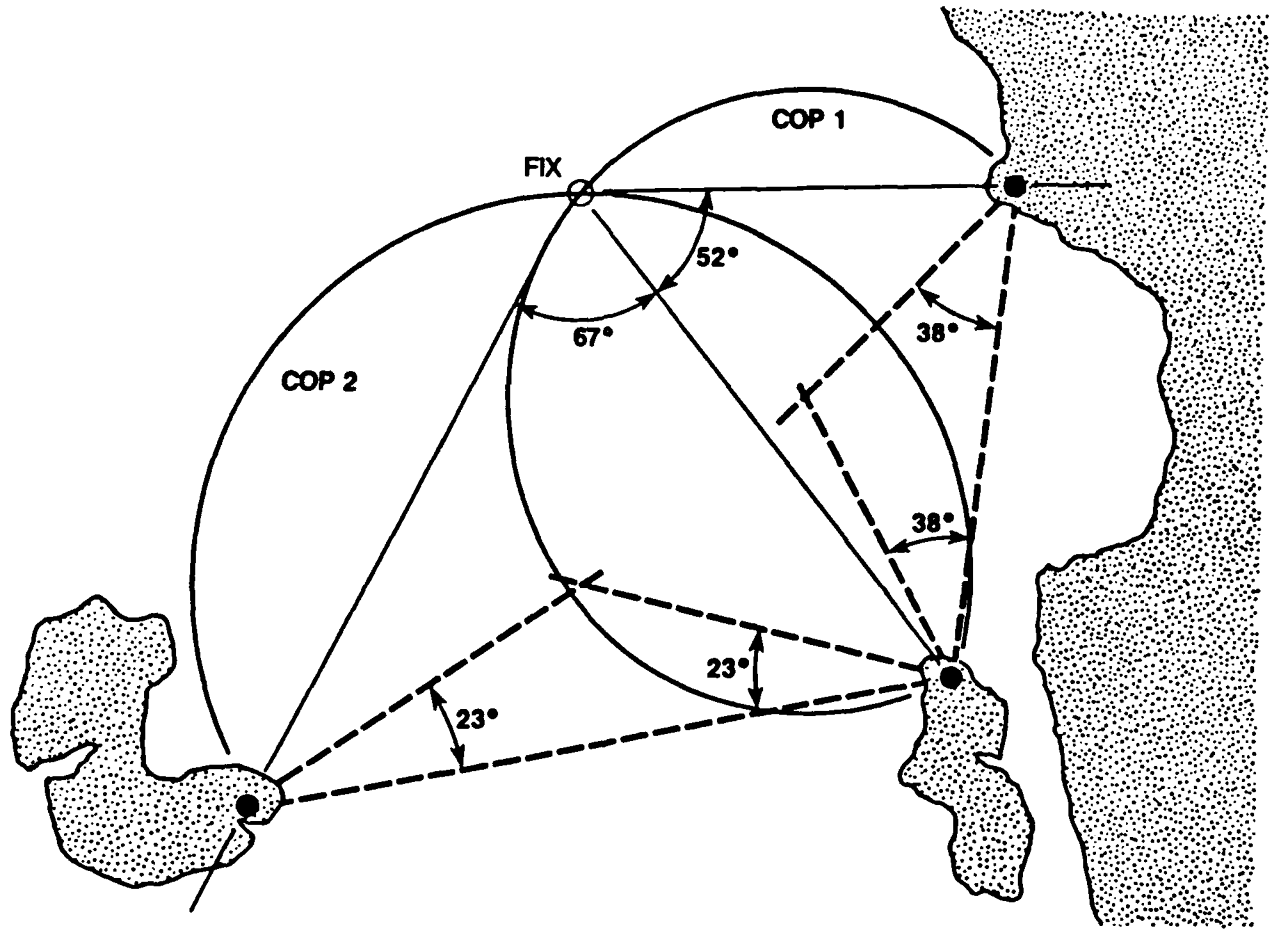


Figure 2. Station fix using position circles.

in the plot of a second COP. In the example, the second angle is 67°, requiring a plot of radius lines at 23° from the baseline. The intersection of the two position circles marks the vessel's location.

Position fixes normally are plotted with a station pointer or a three-arm protractor (Figure 3). The two measured angles are set by moving and locking the two outer arms of the protractor, which then is moved over a nautical chart until the three arms align with the preplotted locations of the shore targets. The vessel's position is recorded at the center of the protractor. Because this procedure can be implemented in 10-15 sec with some experience, it commonly is used in hydrographic surveys where moving vessel positions are needed. To minimize the parallax error, the two sextant operators should stand as close as possible when making the measurements. Sextant angles can routinely be measured to approximately 1 min of arc or better, depending upon the instrument quality and operator ability. Within 5 km (3.1 mi) of shore stations and at acceptable COP crossing angles, the resulting accuracy in position is 1 part in 2,500 or about ± 2 m (6.6 ft) (Ingham 1975).

Sextant angle resection has many advantages as a positioning technique, including its relatively high accuracy, ease of implementation, and nominal cost of the sextants and the three-arm protractor. Also, no shore party is required. The procedure does have some limiting factors, however. Range is ultimately limited by visibility and by the sizes, elevation, and placement of the shore targets. Also, it is imperative to follow procedures in locating targets to avoid indeterminate or weak fixes. For example, a fix cannot be obtained when the vessel and all three shore targets lie on a common circle (called the danger circle). This can be avoided by aligning the shore targets along a straight line, which causes the radius of the danger circle to become infinite. Another recommended practice to assure strong fixes is to place targets so that intercepted angles fall between 30° and 140° (ideally between 45° and 60°), thereby maintaining large position circle cut angles. Shore targets also may be placed on a curve convex to the observer, with the middle target nearest the sampling vessel (Figure 4). Alternately, targets may lie on a curve concave to the vessel, provided that the anticipated positions are within the triangle

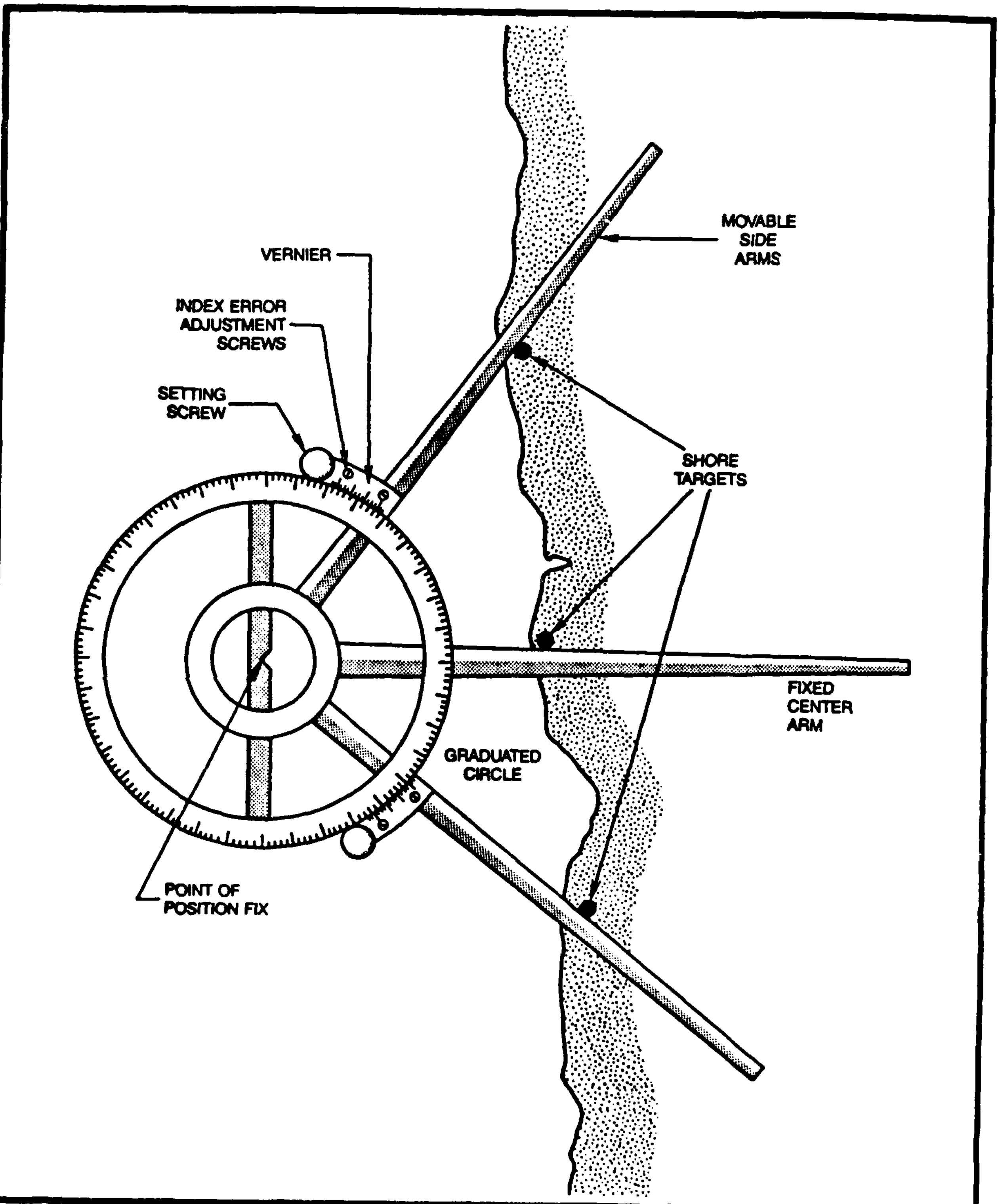
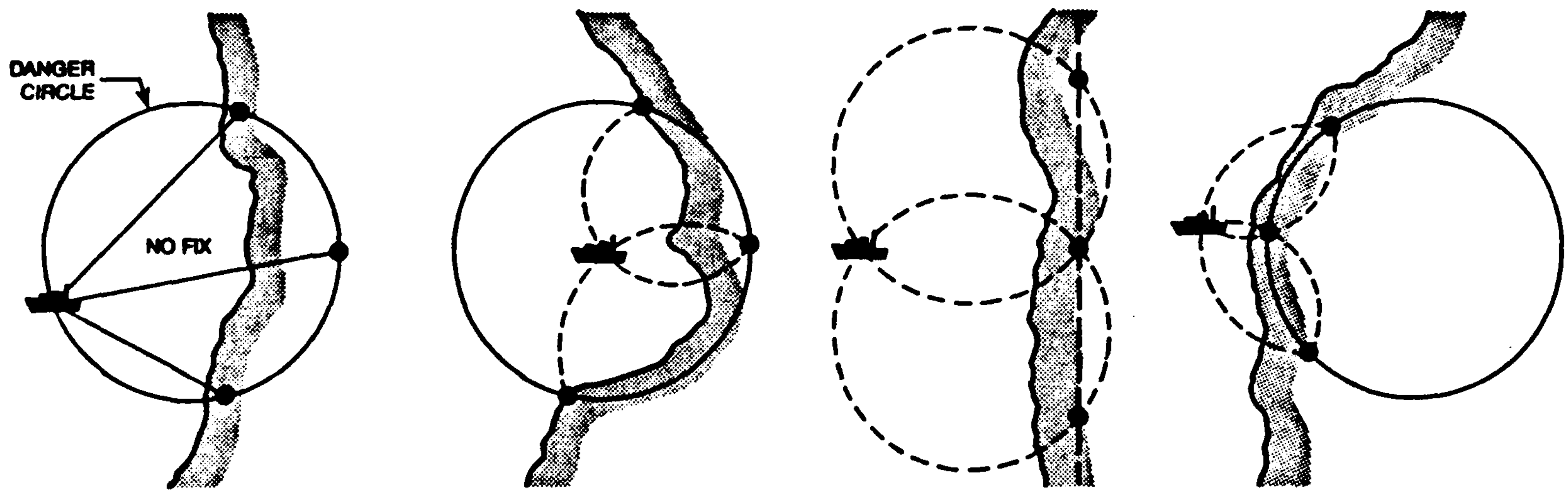


Figure 3. Three-arm protractor for sextant resections.



Adapted from Ingham 1975

Figure 4. Shore target locations to avoid the danger circle.

formed by them, they are virtually equidistance from the vessel, the observed angles are not less than 60°, or the vessel is well outside the circumscribing circle (Clark 1951; Davis et al. 1966).

At the limits of visibility, sextant angle fixes are likely to be weak because the angles are small. In such cases, large positional errors can be caused by small errors in the angles themselves (Umbach 1976). This problem can be partially offset by using a telescope mounted on the sextant. Sextants must be in perfect adjustment and angles must be read with extreme care. Also, the sextant must be of superior quality so that the angles may be read to the necessary precision. When working at locations near shore, the sum of the two angles can approach 180°, with one angle often very large and the other very small. Under such conditions, care must be taken to mark the two angles simultaneously if the vessel is moving, or to make several measurements if the vessel is on station, because the angles rapidly change with slight vessel movements.

Split-fixes (no common center object) may be taken when a three-point fix is not possible. The vessel position is at the intersection of two angle loci. A fix is considered strong when the intersection angle is greater than 45°. While shoreline tangents can be taken when no other objects are available, these fixes are inaccurate in most cases. Split fixes and shoreline tangents should be used only when absolutely necessary. They are inefficient due to the required recording procedures and plotting time, and they cannot generally be entered into automatic data processing and plotting systems.

Sextants are classified as vernier or micrometer drum types, the latter preferred by most users. A well-constructed metal marine sextant is capable of measuring angles with an instrument error not exceeding 10 sec or 0.1 min of arc (Bowditch 1977). However, as indicated earlier, positional error will be highly dependent on operator ability. For accurate work, a sextant having an arc radius of 162 mm (6.4 in) or more should be selected. Characteristics of representative sextants are presented in Table 4. Sextants should be adjusted prior to start of disposal operations and verified at

TABLE 4. MARINE SEXTANT CHARACTERISTICS

SPECIFICATIONS	C. PLATH NAVSTAR CLASSIC	NAVSTAR PROFESSIONAL	TAMAYA SPICA	TAMAYA JUPITER (UNIVISION)	TAMAYA VENUS	WEEMS& PLATH
Arc Range	-5 to +125^0	-5 to +125^0	-5 to +125^0	-5 to $\pm$125^0	-5 to +125^0	-5 to +125^0
Instrument Accuracy	< $\pm$10"	< $\pm$10"	< $\pm$10"	< $\pm$12"	< 18"	< $\pm$10"
Vernier Scale	0.2'	0.2'	0.2'	0.2'	0.2'	0.2'
Arc Radius (mm)	162	162	162	162	138	162
Telescope	4X40 6X30	4X40	4X40(7^0) 7X35(6.5^0)	4X40(7^0) 7X35(6.5^0)	3X26	4X40 6X30
Brightness			100/25	100/25	75	
Index Mirror (mm)	57X41	57X30	57X42	57X42	45X30	57X41
Horizon Mirror Dia. (mm)	57	57X30	57	57	45	57
Illumination	Arc & Drum	Yes	Arc & Drum	Arc & Drum	No	Arc & Drum
Frame Mtl.	Brass/Alloy	Makrolon	Aluminum	Aluminum	Aluminum	Brass
Arc Mtl.	Brass/Alloy	Al. Alloy	Bronze	Bronze	Bronze	Brass
Case	Mahogany	Plastic	Plastic	Plastic	Wood	Mahogany
U.S. Suggested List Price (1/85)	$1270	$965	$919	$715	$585	$1674

the conclusion, or at least once a week, whichever is more frequent. Any index correction should be recorded in the log. Procedures for sextant adjustment are provided by Umbach (1976) and Bowditch (1977).

Considering the achievable accuracy when the double horizontal sextant angle method is properly implemented, this procedure offers an inexpensive candidate positioning method for disposal barges. Operators can head toward a predetermined heading and range, uing pre-set sextant cutoff angles to know when to dump. However, the method may be ineffective during poor visibility. Also important is the need to construct, survey, or maintain the sufficient number of properly located shore targets to provide positioning at each disposal site. Overall, the method has merit if the cost of an electronic positioning system cannot be justified.

As a potential monitoring tool, there are important limitations that should be considered. Either the monitoring agency must supply two personnel on the vessel during the disposal operations, or the requirements for specific fixes and acceptable deviations from those fixes must be included in the disposal permit. The latter would rely on user determination of location at the time of the dump with no independent verification. Acceptability of records as evidence would rely on usability of the captain's log (or special dump log) for legal purposes.

Variable Range Radar

While technically not an optical positioning technique, obtaining ranges from a variable range radar (VRR) consists of two optical estimations by the user (target location and bearing of radar reflection) and will be addressed herein. A position can be fixed by measuring the distances to three targets on the radar screen that can be identified accurately on a map. A third fix will reduce the chance of error and increase accuracy. A variable range marker measures the distance to the object (as identified by its radar reflection). This distance then is drawn with a compass as a line of position (LOP) on the nautical chart. The intersection of the three LOPs marks the vessel's position.

Most commercial vessels are equipped with radar for safety and navigation. Coastal vessel radar usually have ranges from 26 to 116 km (16 to 72 mi). A variable range marker (VRM), whether built-in or added on to the existing on-board radar, removes a large portion of operator error in estimating distances. For positioning at accuracies less than 300 m (984 ft) at distances from shore greater than 1000 m (3280 ft), a VRM almost always is needed. Range accuracies with the VRM are usually 0.5 to 2 percent of the range scale, or ±25 m (82 ft) at 0.5 km (0.3 mi), the smallest scale. Accuracy decreases as the range scale is increased. Bearing accuracy is usually less than 1°. Characteristics of representative VRRs are presented in Table 5. Generally, analog systems have better resolution than digital systems, but are not as versatile.

Each position fix will rely on the resolution and identification of the radar reflection. Resolution of the target position will change with the range scale. Reflections will depend upon target position and alignment. The location of the reflection is not always easy to identify. Placement of the cursor away from the actual reflection surface will introduce error into the fix. Estimation of the radar target location in relation to the chart's mapped structures is important. Misidentification of a reflection source will result in plotting a position at the wrong coordinate, but will not affect repeatable accuracy. Certain regions, such as sloped headlands and tidal flats, give inaccurate reflection because it is impossible to relate the reflection to a map location. The most accurate radar range fixes are obtained from solid reflections between 0.16 and 6.4 km (0.1 and 4 mi). This keeps the range scale low, resulting in accuracies greater than 40 m (131 ft) and avoids erroneous readings caused from very close reflections.

Positioning barges with VRR should provide sufficient accuracies for a 274-m (900-ft) radius dump zone in almost any type of weather. Providing range limitations to predetermined targets identified by the regulatory agency will reduce the radial error even further. Most tugs already are equipped with VRR and other radar can add variable range markers for $1,000 to $2,000. The newer digital systems, priced in the $5,000 to $10,000

TABLE 5. VARIABLE RANGE RADAR (VRR) SYSTEM CHARACTERISTICS

Systems	Model	Type	Variable Range Markers	Range (km)	Nominal Accuracy Range (m)	Nominal Accuracy Angle	U.S. Suggested List Price[a]
DECCA Racal DECCA Marine Redmond, WA (206) 885-4713	RD170 VRM/VP3	Digital	1 (add-on)	77	-	$\pm 0.5^\circ$	$3,990
	RD170 BT	Digital	1	77	± 30 at 0.4 km	$\pm 0.5^\circ$	$6,000
Furuno U.S.A. San Francisco, CA (415) 873-9393	FR-360 MKII	Analog	add-on	58	± 25 at 0.5 km	$< \pm 1^\circ$	$4,400 without VRM
	FR-810	Digital	2	116	± 36 at 0.5 km	$< \pm 1^\circ$	$7,400
	FR-1011	Analog	1	77	± 25 at 0.5 km	$< \pm 1^\circ$	$8,300
KODEN/SI-TEX Norwell, MA (617) 871-6223	T-100	Digital	1	26	± 22 at 0.5 km	$\pm 0.5^\circ$	$2,200
Raytheon Marine Seattle, WA (206) 285-6843	3604	Analog	1	58	-	$\pm 1^\circ$	$4,900
	3610	Analog	1	116	-	$\pm 1^\circ$	$5,400

[a] December, 1985.

range, offer multilevel processing for better target pickup and provides map plotting ability on the screen.

ELECTRONIC POSITIONING TECHNIQUES

Electronic positioning methods use the transmission of electromagnetic (EM) waves from two or more shore stations and a vessel transmitter to define a vessel's location. The systems are based on the ability to predict variations in EM wave travel velocity as a function of travel path. Position is determined by measuring differences in signal arrival times (range-range mode) or by comparing the phases of received signals to that of the transmitted signal (hyperbolic ranging).

At their respective maximum ranges, electronic positioning methods have higher accuracies than visual methods. Measurements can be obtained regardless of weather and visibility conditions, and operating ranges are typically much greater than for optical methods. Range can be extended to 50-100 km (31-62 mi) simply by elevating antennae until signal attenuation becomes a limiting factor. Shore stations need not be attended, minimizing personnel requirements. Positional readouts are available as distances or coordinates, rather than wavelengths or time delays, and deck units are usually compatible with data processing and automatic plotting equipment. Position information is continuous, enabling maintenance of a desired location by dynamic positioning or by traversing along a predetermined path. Some of these methods also are used as the basis for monitoring methods discussed later in this document.

The short-range systems of primary importance are compact, lightweight, durable, easily calibrated, and relatively stable. Disadvantages of electronic systems can include cost, particularly for smaller program requirements, the inconvenience of orienting shore and on-board units, vandalism of shore stations, and unknown signal propagation effects (although this should not be a problem over the relatively short distances to disposal sites in Puget Sound). As discussed later, costs can be minimized by sharing the expense among multiple users, by leasing equipment during site use, or by contracting for survey personnel and equipment.

System Classifications

Electronic positioning systems often are classified by range capability, which depends largely upon propagation characteristics of the operating signal. Band width and signal power also influence range capability. Electronic positioning methods are herein categorized as short-range, medium-range, and long-range systems. Although short-range systems are emphasized, other categories also are examined because methods such as Loran-C are frequently used in parts of Puget Sound. Satellite navigation systems also are presented because their prices are declining and capabilities (i.e., coverage and repetitive access) are expected to increase. Categories of electronic positioning systems, including operating frequencies, wavelengths, ranges, and representative commercially available equipment, are listed in Table 6.

Short-range [0-40 km (0-25 mi)] microwave systems are portable and best suited for use in the range-range mode. Medium-range systems [to 150 km (93 mi)] also are transportable, although components usually are bigger and heavier. They are effective in either the range-range or hyperbolic mode. Long-range [to 2,000 km (1,243 mi)] and global systems transmit from permanently installed, widely dispersed shore stations or satellites for multiuser operation.

Comparative Absolute Accuracies

Although it is difficult to specify the positional accuracies achievable by instruments in each category, some generalizations can be made. Whereas the optical methods discussed can provide accuracies of ±2 m (6.6 ft) for ranges up to 5 km (3.1 mi) offshore, short-range electronic positioning methods may provide accuracies of ±1-3 m (±3.3-9.8 ft) for ranges up to 40 km (25 mi) from shore stations. Comparable medium-range system accuracies are ±5.0 m (16 ft) up to 150 km (93 mi). Long-range systems typically have accuracies of ±50-100 m (164-328 ft) within 350 km (217 mi) of shore stations, and more than 100 m (328 ft) at greater ranges.

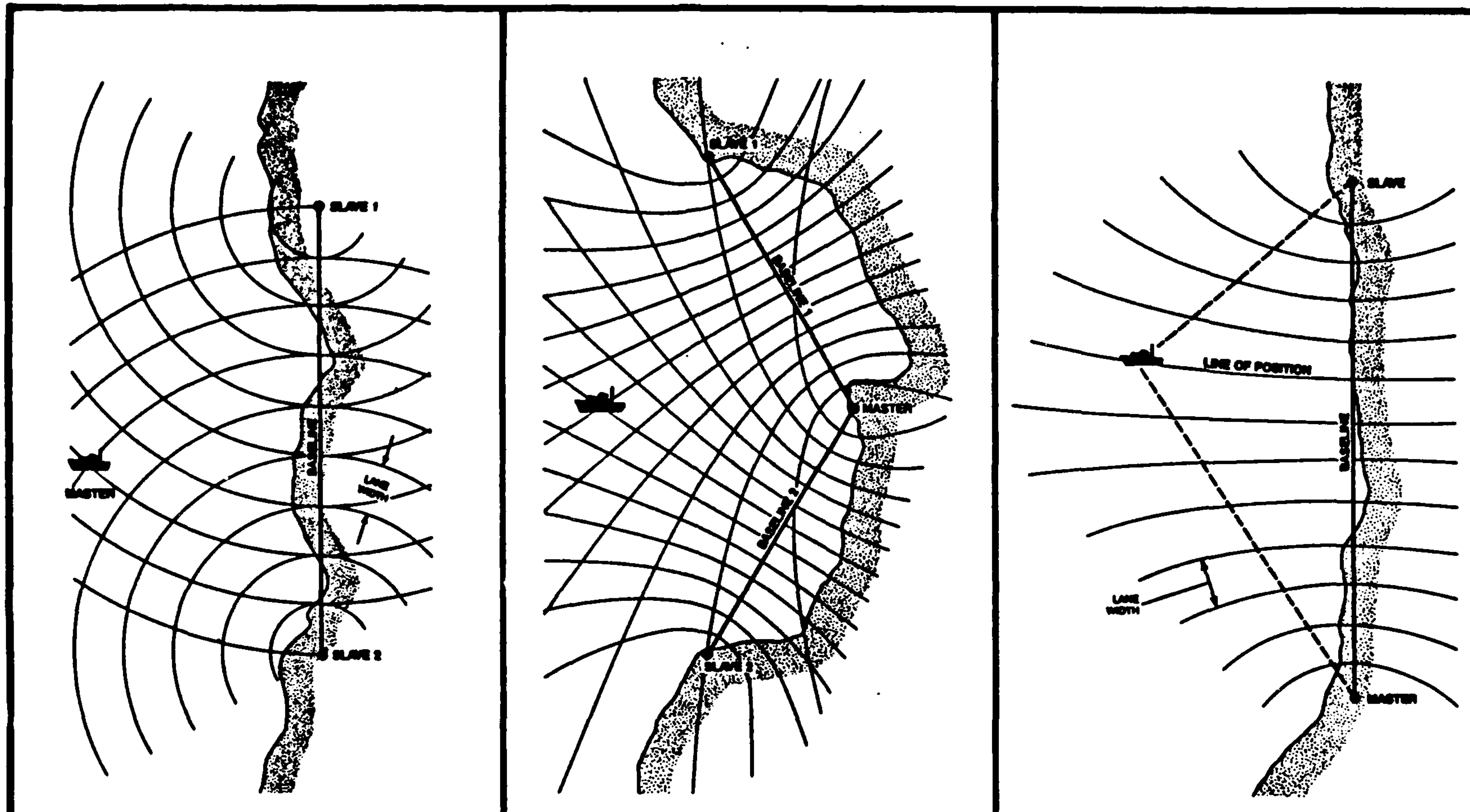
TABLE 6. ELECTRONIC POSITIONING SYSTEM CATEGORIES

Category	Range	Representative Systems
Very long range	>2,000 km	OMEGA
		TRANSIT (NAVSAT)
Very low frequency		GEOSTAR
Satellite		NAVSTAR GPS
		SERIES
		AERO SERVICE GPS
Long range	0-2,000 km	LORAN-C
		VIEWNAV
Low frequency		LAMBDA
Medium range	0-150 km	SYLEDIS
		RAYDIST TRAK IV
Medium-high frequency		HYPER-FIX
		ARGO DM-54
		HYDROTRAC
Short range		
Radar	0-100 km	DECCA
		FURNO U.S.A.
		KODEN/SI-TEX
		RAYTHEON MARINE
Microwave	0-40 km	TRISPONDER
		MINIRANGER
		MICRO-FIX
		HYDROFLEX
		AUTOTAPE
		AZTRAC
		POLARFIX
		ARTEMIS

Operating Modes

Two principal radio navigation system operating modes include the two-range (or range-range) mode and the hyperbolic mode. Some systems incorporate the advantages of each in a combination mode. These three modes are presented in Figure 5. In the range-range mode, position fixing is accomplished by measuring the extremely small time intervals required for EM signals to travel from an on-board master transmitter to one or more onshore slave stations, and back (Figure 5a). For a known propagation velocity, the time interval is converted to a distance (range) from the slave, defining a single circle of position on which the vessel may lie. The intersection of two or more such circles (based on signal returns from two or more slave stations) results in a position fix. This operating mode usually is restricted to a single user, although single side-band techniques have been employed to allow multiuser operation (Ingham 1975). Lane width (distance between points of zero signal phase) remains constant regardless of distance from the system baseline. The lane width resolution does not decrease at increasing ranges from the baseline, as is the case in the hyperbolic positioning mode.

In the hyperbolic mode, the on-board receiver detects the phase difference of signals arriving from multiple shore-based transmitters. Lines of constant phase between master and slave transmitters form a hyperbolic pattern of position lines (Figure 5b). By measuring the phase difference between arriving signals, the vessel can be located along one of the position hyperbolas. Adding a second master-slave transmitter pair superimposes another hyperbolic pattern, resulting in a grid network with pattern crossings (Figure 5c). Measurement of the signal phase difference from the second transmitter pair allows vessel positioning on the second pattern, and therefore "unambiguous" location at the applicable grid crossing point. Phase differences usually are resolved to 1/100 of the lane width. Resolution of the hyperbolic system matches that of a range-range system only along the master-slave transmitter baseline. Because of lane widening for increasing range from the baseline, the system resolution decreases with vessel distance from the master-slave transmitter baseline. As indicated earlier, the angle-of-cut of arriving signals also affects the magnitude of position error.



A. RANGE-RANGE GRID CONFIGURATION

B. HYPERBOLIC PATTERN

C. HYPERBOLIC GRID CONFIGURATION

Figure 5. Operating modes for radio navigation systems.

In hyperbolic systems, extending the baseline length improves cut-angles of the arriving signals and decreases lane spreading (Ingham 1975).

Short-Range Systems

Electronic Distance-Measuring Instruments--

A position fix is obtainable with two electronic distance-measuring instruments (EDMI), or one EDMI with an angle measurement by theodolite or sextant. Distance-measuring instruments that are either electro-optical (e.g., laser) or electronic (e.g., microwave) are discussed herein. Electro-optical and microwave distance-measuring devices are extensively used in land-based surveying. The EDMI master generates a carrier signal which is directed toward a reflector (in the case of light beams) or a repeater (for microwaves). The light or microwave beam is modulated at two or three different frequencies, usually under the control of a precision quartz crystal oscillator. A phase comparison of the incoming and outgoing beams enables accurate distance determinations.

The EDMI is relatively new in the surveying field. The geodimeter of the early-1950s, which used a modulated light beam, was replaced in the late-1950s by the Tellurometer, which used a modulated microwave signal. This improvement increased the range and allowed operation in moderate rain, fog, and darkness. Newer EDMIs have shorter ranges, but due to the use of solid state electronics, are much more compact, less power-intensive, and easier to read. The newest EDMIs use highly coherent laser light, have longer ranges, require even less power, are portable, and are easy to operate. The so-called "total station" consists of a theodolite for measuring angles and an EDMI for measuring distances, with outputs recorded on magnetic or paper tape for subsequent analyses. Under favorable conditions, EDMI range capabilities are 1.6 km (1 mi) for light-based systems, 80 km (50 mi) for laser systems, and 150 km (93 mi) for microwave systems.

Properly adjusted and calibrated, an EDMI has few sources of error. Ground wave reflection can cause error when measurements are made over water because reflected signals result in faulty distances due to the longer

path lengths. The swing, or cyclic manner, in which reflections are recorded must be correctly interpreted. At very close range, EDMI accuracy is limited by a constant of uncertainty. Beyond 0.5-1.0 km (0.3-0.6 mi), accuracies of 1 part in 25,000 are easily achieved. If meteorological conditions over the signal path are sufficiently well-known, accuracies of 1 part in 100,000 can be achieved (Moffitt and Bouchard 1982). Characteristics of representative short- and long-range electro-optical and microwave distance measuring devices are presented in Table 7. As indicated, instruments with a range of 25 km (16 mi) can be used to measure distances to within 5 cm (2 in), while shorter-distance devices [to 5 km (3.1 mi)] are accurate to 1.5-3.0 cm (0.6-1.2 in)].

It is apparent, therefore, that accuracies achievable with electronic distance measurement devices are more than adequate to meet the positioning requirements for disposal operations. In fact, it is the angle-measuring devices used with EDMIs that limit accuracy, not the EDMI itself. Probably the major disadvantage of EDMIs is the continual motion and resultant misalignment of the reflector and loss of signal (in electro-optical systems). Use of microwave patterns eases directive requirements.

Total Stations--

An electronic tachymeter, commonly referred to as a total station, is an instrument for determining the distance, bearing, and elevation of a distant object. In coastal surveys it is a shore station instrument used to sight the survey vessel reflectors, enabling positional information to be recorded onshore for subsequent communication to the vessel operator. In a manual station, the same telescope optics (co-axial) are used to measure both distance and angles. They basically are theodolites with built-in EDMI units. With such manually operated units, slope reduction of distances is done by optically reading the vertical angle and keying it into a built-in or hand-held calculator (McDonnell, Jr. 1983). A semiautomatic total station contains a vertical angle sensor for automatic slope reduction of distances, while horizontal angles are read optically. With an automatic station, both horizontal and vertical angles are electronically read for use with slope distances in a data collector or internal computer. A theodolite

TABLE 7. ELECTRONIC DISTANCE MEASURING INSTRUMENTS

COMPANY	MODEL	RANGE(m) SINGLE PRISM TRIPLE PRISM MAXIMUM(prisms)	ACCURACY (MSE)	U.S. SUGGESTED LIST PRICE
Benchmark Orlando, FL (305)281-5000	Surveyor III-X	1600 3000 3500(6)	±(5 mm + 5 ppm)	$3,495
Geodimeter, Inc. Novato, CA (415)677-1256	Geodimeter 14-A	6000 8000 15000	±(5 mm + 3 ppm)	$11,300
	Geodimeter 112/122	2500 3600 6000(8/16)	±(5 mm + 3 ppm)	$6,250(112) $10,950(122)
	Geodimeter 220	1600 2400 3200(8)	±(5 mm + 3 ppm)	$8,850
Kern Instruments Brewster, NY (914)279-5095	DM 503	2000 3500 4500(7)	±(3 mm + 2 ppm)	$8,995
Keuffel & Esser, Co. Morristown, NJ (201)285-5000	Ranger V-A (HeNe Laser)	8000 16000 25000	±(5 mm + 2 ppm)	$20,561
	PulseRanger	1000 3000	±(30 cm + 150 ppm)	$7,500
The Lietz Company Overland Park, KS (913)492-4900	RED 2A/2L	2000/3800 2800/5000 ----/7000(9)	±(5 mm + 5 ppm)	$4,695(2A) $5,795(2L)
MK Electronics, Inc. Littleton, CO (303)795-2060	MK-III, MK-III VS	1600 3000 4000	±(5 mm + 2 ppm)	$5,950(III) $7,950(III-VS)
Nikon, Inc. Garden City, NY (516)222-0200	ND 31	1900 3200	±(5 mm + 5 ppm)	$5,885
Pentax, Corp. Englewood, Co (303)733-1101	PM-81	1400 2000	±(5 mm + 5 ppm)	$4,790
Teludist, Inc. Mastic Beach, NY (516)399-5843	Tellemat CMW20 (microwave)	25000	±(5 mm + 3 ppm)	$16,500
Topcon Instrument Corp. Paramus, NJ (201)261-9450	DM-S3	2000 2500 2900(9)	±(5 mm + 5 ppm)	$5,390
Wild Heerbrugg Farmingdale, NY (516)293-7400	Citation-450	1600 2300 4000(11)	±(5 mm + 5 ppm)	$3,995
	DI-4L Distomat	2500 3500 7000(11)	±(5 mm + 5 ppm)	$8,995
	DI-20 Distomat	6000 7000 14000(11)	±(3 mm + 1 ppm)	$14,995

with a mount-on EDMI usually is not classified as a total station. An exception is the modular total station, where the design objective is flexibility of future additional equipment. Such units usually are designed around an electronic (digitized) theodolite such as the Kern E1. Many total stations are designed to make full use of hand-held calculators (e.g., the HP-41CV) for data storage, computations, access to control registers, testing, calibration, and orthogonal offset determinations. Most manufacturers offer optional data collectors that serve as electronic supplements to field books. This permits a convenient interface with a computer and remote transmission of data using an acoustic modem.

Characteristics of representative total stations are presented in Table 8. As indicated, range is dependent upon the number of prisms available for signal reflection. Such prisms are directional (i.e., must be pointed towards the shore station), as opposed to omnidirectional prism arrangements used for range-azimuth navigation systems. Directional prisms cost approximately $300 for a pair and $500 for a set of three. Although systems requiring 9 to 11 prisms are expensive, they allow measurements regardless of vessel orientation. Some manufacturers report displaying angles or accuracies to 1 sec or less. However, experienced surveyors know that this level of accuracy requires careful or repeated pointings at good targets.

For both positioning and monitoring programs, single station capability is attractive. Setup and calibration efforts are minimized, and the logistics of station movement are much simpler than with a multi-station net. The system can be used both for positioning of the vessel and monitoring with a single radio link. A total station can be used on other projects when not in use for periodic monitoring. The $8,000 to $30,000 price range is competitive with the microwave positioning systems ($40,000 to $100,000), and achievable accuracies in both range and angle are more than adequate. Instrument capabilities and costs are reported in the free, bimonthly journal Point of Beginning [P.O.B. Publishing Company, Wayne, MI (313-729-8400)].

TABLE 8. TOTAL STATION CHARACTERISTICS

COMPANY	MODEL	TYPE	RANGE* (km) L	RANGE* (km) M	RANGE* (km) H	PRISMS	ACCURACY RANGE	ACCURACY ANGLE	U.S. SUGGESTED LIST PRICE
Carl Zeiss, Inc.	RMS3	Semi-Auto	-	1.5[a]	-	1	±5-10 mm + 2ppm	±2"	$8,260
Thornwood, NY			-	2.0[b]	-	3			
(914)848-1800			-	3.0[c]	-	9			
	Elta 3	Automatic	-	1.6	-	3	±10 mm + 2ppm	±2"	$18,725
			-	2.5	-	6			
			-	3.0	-	18			
	Elta 46R	Automatic	-	2.0	-	3	±10 mm + 2ppm	±3"	$12,820
Geodimeter, Inc.	140	Automatic	1.2	2.2	3.0	1	±(5mm + 5 ppm)	±2"	$19,950
Novato, CA			1.8	3.0	4.0	3			
(415)883-2367			2.4	3.8	5.5	6			
			3.6	4.8	6.0	8			
Kern Instruments	E1/DM503	Automatic	1.5	2.5	3.0	1	±(3 mm + 2 ppm)	±2"	$19,175
Brewster, NY	E2/DM503		2.0	3.5	4.5	3	±(3 mm + 2 ppm)	±0.5"	$22,375
(914)279-5095			2.4	4.5	5.5	7			
Lietz	SMD-3	Manual	-	0.8	1.2	1	±(5 mm + 5 ppm)	10" digital	$8,800
Overland Park, KS	SDM-3ER	Semi-Auto	-	1.4	1.8	3		5" direct	$10,800
(913)492-4900	SET-10	Automatic	-	-	2.5+	9			$14,000
MK electronics	MK-III	Automatic	-	3.0	-	3	±(5 mm + 2 ppm)	6"	$12,950
Littleton, CO	MK-IV		-	4.0	-	3	Stationary		$14,950
(303)795-2060	MK-HYDRO		-	3 or 4	-	3	±(20 mm + 5 ppm) Moving		$16,950
Nikon Instruments	NTD-4	Manual	-	1.2	1.6	1	±(5 mm + 5 ppm)	6" digital	$8,595
Garden City, NJ			-	1.8	2.3	3		3" subdivision	
(516)222-0200	NTD-1	Automatic	-	1.2	1.6	1	±(5 mm + 5 ppm)	1"	$15,985
			-	1.8	2.3	3			
Pentax	PX-10D	Manual	-	1.4	-	1	±(5mm + 5 ppm)	10" digital	$8,450
Englewood, CO			-	1.7	-	3		5" direct	
(303)773-1101								2" estimation	
	PX-06D	Manual	-	1.4	-	1	±(5 mm + 5 ppm)	6" digital	$8,765
			-	1.7	-	3		1" estimation	
Topcon	GTS-2B	Manual	-	1.4	1.7	1	±(5 mm + 5 ppm)	6"	$7,990
Paramus, NJ			-	2.0	2.4	3			
(201)261-9450			-	2.6	3.0	9			
	ET-1	Automatic	-	1.4	1.7	1	±(5 mm + 5 ppm)	2"	$14,250
			-	2.0	2.4	3			
			-	2.6	3.0	9			
Wild Heerbrugg	T2000+	Automatic	1.2	2.5	3.5	1	±(5 mm + 5 ppm)	0.5"	$24,000
Farmingdale, NY	DI4L or		1.5	3.5	5.0	3	±(3 mm + 2 ppm)		$25,000
(516)293-7400	DI5		1.7	4.5	6.0	7			
			1.8	5.5	7.0	11			
	T2000+	Automatic	2.0	6.0	9.0	1	±(3mm + 1 ppm)	0.5"	$30,000
	DI20		2.3	7.0	11.0	3			
			2.6	8.0	13.0	7			
			2.7	9.0	14.0	11			

* Atmospheric visibility a. low = hazy, 5km b. medium = clear, 15km c. high = very clear, 30km

Microwave Navigation Systems--

Short-range electronic positioning systems generally operate at microwave frequencies that limit the system ranges to "radio line-of-sight." Typically, such systems are effective between 25 and 100 km (16 and 62 mi) offshore, depending on antenna heights and power outputs. Position measurements are indirect (i.e., by timing the travel of multiple pulsed signals from a master to two or more remote stations and back; alternately, phase differences between arriving signals can be measured). Available systems operate in the range-range mode, the hyperbolic mode, or both. The position fix is defined by the intersection point of two position circles or hyperbolic constant-phase lines. Because microwave systems have nominal accuracies of ±1-3 m (±3.3-9.8 ft) from very short ranges to 25-40 km (16-25 mi), they provide adequate capability for barge positioning. Potential limiting factors include problems with shore station security, and signal interference in industrial areas or in the vicinity of radar-intensive military installations. Autorecording units would need to be set up for monitoring, and would record the track of the vessel. However, the problem of determining the actual dumping period still exists. Characteristics of representative microwave navigation systems are summarized in Table 9.

<u>Trisponder</u>--The Del Norte Trisponder is an X-band (8,800-9,500 MHz) positioning system composed of a digital distance-measuring unit (DDMU), a master station (usually on the vessel), and two remote stations located at known geographic positions. Each station is a combined transmitter and receiver. The master station antenna is omnidirectional and each remote station has a directional antenna. Distances to remote stations are observed on the DDMU using the range-range mode. A time-sharing feature allows up to eight users.

The manufacturer quotes a typical range accuracy of ±1 m (±3.3 ft), with an instrument resolution of 0.1 m (0.3 ft). In <u>The Hydrographic Manual</u>, Umbach (1976) cites a range error for this system of ±3 m (±10 ft), with good field conditions, based on the Trisponder Basic Operation Manual published in 1974. Also cited were tests conducted by the National Ocean Survey (date unknown), which indicated that temporal electronic drift may cause

TABLE 9. SHORT-RANGE POSITIONING SYSTEM CHARACTERISTICS

SYSTEM	RANGE (km)	FREQUENCY (MHz)	NOMINAL ABSOLUTE ACCURACY (m)	USER CAPABILITY	ANTENNA Vessel	ANTENNA Shore Station	COST
TRIPSONDER (520/540 DDMU) DEL NORTE Technology, Inc Euless, TX (817)267-3541	5 80 80	9320-9500(261) 9329-9500(217E) 8800-9000(218E)	± 1	up to 8 (more optional)	360°H 20°V	$87^\circ/180^\circ$H $6^\circ/50^\circ$V	$40,000
FALCON 484 Mini-Ranger Motorola, Inc. Tempe, AZ (602)897-4376	37	5410-5600	± 2	up to 20	360°H 25°V	70°H 15°V	$39,300
MICRO-FIX Racal DECCA Survey, Inc. Camarillo, CA (805)987-8080	80	5480 5523 5560	± 1	up to 16	360°H 20°, 30°V	90°H $6^\circ/30^\circ$V	$43,000
HYDROFLEX Teludist, Inc. Mastic Beach, NY (516)399-5843	100	3000	± 1 plus 3×10^{-6} distance(m)	single multiuser option	360°H 18°V	Long-range 24°H, 22°V Fan Beam 18°V, 60°H	$63,500
AUTOTAPE DM-40A/DM-43 Cubic Western Data San Diego, CA (619)268-3100	150	2900-3100	± 0.5 ± 1:100,000 range	single	360°H 10°V	30°-120°H 10°V	$90,000

*January 1985

measurement variations. Recalibration is suggested over a measured base line after every 200 h of operation. However, the tests were conducted on a Model 202 Trisponder Surveyor System for which the manufacturer claimed a resolution of 3 m (10 ft) and a positional accuracy of $\pm$3 m ($\pm$10 ft), after field calibration.

The currently available microwave system operates with Model 217/218E transponders and Model 520 or 542 DDMUs. The Model 261 transponder, usable as a master or remote, has a 5-km (3.1-mi) line-of-sight range. The Model 217/218E transponders operate up to 80 km (50 mi) from shore due to higher output power. The transponders are designed for use with either of the DDMU models. The Model 520 will collect four ranges and display two. The Model 542 interrogates four remotes, outputs four sets of data, and also provides a positioning guidance capability. The cost of a complete system, including a Model 520 DDMU, a master and two remote 217E/218E transponders, and antenna, is $40,000 (Buchanan, C., personal communication). For the additional guidance capability of the Model 542 DDMU, the system cost is $44,500. A less expensive "black box" version of the DDMU (Model 562) is available for use with an existing shipboard computer system, allowing more than eight users. Cost of the Model 562 and other required components is $39,500.

Falcon 484 Mini-Ranger--The Motorola Falcon 484 is a C-band (5,410-5,600 MHz) microwave ranging and positioning system that operates in the two-range mode from 100 m (328 ft) to 40 km (25 mi). The system consists of a vessel receiver-transmitter assembly with an omnidirectional antenna, a range console, and shore-based radar transponders with directional antennae. Pulsed radar from the vessel transmitter interrogates radar transponder reference stations located at geographically known points. Elapsed time between transmitted interrogations and the reply from each transponder is used as the basis for range determinations. Two ranges are used for trilateral positioning. If three or four ranges are available, range residuals, sum of squared residuals, and error circle radius data are output for the least squares position solution. The manufacturer claims a range accuracy of $\pm$2 m ($\pm$6.6 ft). Up to 20 users can operate in the same area.

The current cost of a basic Falcon 484 system, including a range processor control display, receiver/transmitter with ommidirectional antenna, two reference stations with directional antenna, miscellaneous cables, and manuals is $39,300 (Jolly, J., personal communication). In an effort to eliminate one of the two major problems with most microwave positioning systems (i.e., magneton failures and need to service beacons), Motorola currently is developing a solid-state beacon using a gun diode. The associated increase in long-term reliability also will result in decreased range. However, range capability should remain adequate for positioning needs in Puget Sound. Costs of the modified transmitters were not available at time of publication.

Micro-Fix--The Racal Survey Micro-Fix is a range-range microwave positioning system. With line-of-sight to shore-based transmitters, it is capable of operating up to 80 km (50 mi) offshore. The system normally operates at 5,480 MHz, with options at 5,520 and 5,560 MHz. The master station can interrogate up to eight remote stations (from a possible 32), with each remote transmitter/receiver unit (T/R) preset to recognize its own distinctive station code. Up to four separate station groups can be deployed in the same area without interstation interference. Multiuser capability allows a maximum of 16 users for each deployed chain. Master and remote units are interchangeable.

The basic system consists of a master station with a Control Measurement Unit (CMU), a T/R unit, and two tripod-mounted remote T/R stations. The vessel's master station interrogates the remote stations sequentially, triggering reply pulses received by the master T/R and processed by the CMU to display the corrected ranges. The CMU capabilities include automatic and continuous self-calibration, track guidance, plotter drive, x-y conversion (full spheroid and multi-range solution), and slant range correction. Nominal accuracy is stated by the manufacturer to be ±1 m (±3.3 ft). The cost of a basic Micro-Fix system is $43,000 (Harris, E., personal communication), including training.

The manufacturer is developing the capability to use the system in a hyperbolic mode, a combination range-range/hyperbolic mode, or a range/azimuth

mode, but this capability is not yet available. The system also uses circular polarization techniques to avoid reflective (water surface) signal cancellation nulls, thereby eliminating the need for a second antenna on the vessel. This has been accomplished by an antenna design that prevents signal entrance from reflective angles.

Hydroflex--Hydroflex is a short-range to medium-range microwave navigation system designed for survey applications where a high degree of accuracy is required in fixing or tracking a moving vessel. The system operates at frequencies of 2,920 to 3,300 MHz and has a range of 100 m to 100 km (328 ft to 62 mi). It consists of a master unit controlled by an HP85 computer with a customized software package, an ommidirectional antenna, and connecting cables. Each remote unit consists of a transceiver and either a large range or fan-beam antenna for mounting on a customer-provided tripod. Accuracy is claimed to be 1 m (3.3 ft) $\pm 3 \times 10^{-6}D$, where D is the distance in meters. The system can be operated in either a two- or three-range mode. Although single-user is the normal operating mode, a multiuser option is available. The cost of a master and two remote stations is $63,500 (Baker, W., personal communication).

Autotape DM-40A/DM-43--The Cubic Western Autotape is an S-band range-range microwave positioning system that operates at ranges of up to 150 km (93 mi). System components include a shipboard interrogator and range responders at each fixed onshore station. The DM-43 is capable of working with three geographic sites. Range information is computed by comparing the phase shift of the modulated signal transmitted between the interrogator and responder phase unit to an interrogator reference signal. An Automatic Position Computing System (APCS) is available for steering information, real time analog plot of the vessel's track, and magnetic data recording. For each disposal site, this system can serve as both a positioning aid and a monitoring tool. Again, the actual dumping period is speculation. The system does not accommodate multiple users. The manufacturer claims a range accuracy of 0.5 m plus 1:100,000 times the range distance. This error is due to internal random errors, systematic errors, temperature variation bias errors, signal strength, component aging, and initial calibration errors. External errors are said to far exceed internal noise, systematic,

and bias errors. Index of refraction error, which can approach 5 m (16.4 ft) at 100 km (62 mi), usually is small enough at short ranges to be ignored. Multipath rms errors (dependent on orientation of reflective objects near and behind the interrogator omnidirectional antenna) have been observed from 0 to 3 m (0 to 9.8 ft). The manufacturer states that internal averaging plus external data smoothing will reduce the effect on Autotape to a small fraction of a meter, provided the antenna is moving. For this reason, the system is best suited to applications where the interrogator is on a moving vessel.

The cost of a basic Autotape system including an interrogator, two range responders, and associated antennae is $90,000. The same system with the DM-43 and three shore stations is $124,000 (Hempel, C., personal communication).

Medium-Range Systems

Systems in this category typically operate in the medium- to high-frequency bands (i.e., 1.5-400 MHz), achieving greater ranges using EM waves that propagate around the earth's surface. Positional accuracies of medium-range systems vary from a few meters near the base line to tens of meters at the system's range limits (Ingham 1975). Medium-range systems must be used with caution in inland waters due to the severe landmass attenuation and water-land interface effects. Such effects usually are manifested as large calibration variations within a limited area. Characteristics of representative medium-range electronic position fixing systems are summarized in Table 10. Because of the limited availability, high capital costs, and logistical problems posed by the large-sized land stations, these systems are not further discussed. Other systems offer similar accuracies at reduced costs and are less time-intensive for station setup. Various semi-permanent systems in Table 10 are discussed in detail by Tetra Tech (1986).

Long-Range Systems

Long-range and global navigation systems generally operate at low (30-300 kHz) or very low (less than 30 kHz) frequencies. As in the case

TABLE 10. MEDIUM-RANGE POSITIONING SYSTEM CHARACTERISTICS

SYSTEMS	RANGE (km)	FREQUENCY (MHz)	NOMINAL ABSOLUTE ACCURACY	USER CAPABILITY	ANTENNA VESSEL	ANTENNA SHORE	COST*
SYLEDIS Sercel, Inc. Houston, TX (713)492-6688	300	420-450 406-434	±1 LOS ±3 2X LOS	Up to 4 (Range-range) Unlimited (Hyperbolic)	Not Provided		$ 51,350
RAYDIST Hastings-Raydist Hampton, VA (804)723-6531	278 night 740 day	1.5-2.5	±3	4/net (Range-range) Unlimited (Hyperbolic)	Omnidirectional		$102,200
HYPERFIX Racal DECCA survey Camarillo, CA (805)987-8080	700 day 250 night	1.6-3.4	5-10 0.01 lane display resolution	(Range-range) Unlimited (Hyperbolic)	Omnidirectional		$113,000
ARGO DM-54 Cubic Western Data San Diego, CA (619)268-3100	740 day 370 night	1.6-2.0	4-5 0.05 lane display resolution	Up to 12 (Range-range) Unlimited (Hyperbolic)	Omnidirectional		$188,000
HYDROTRAC Odom Offshore Surveys Baton Rouge, LA (504)769-3051	460 day 230 night	1.6-4.0	2-40 0.01 lane display resolution	Single (Range-range) Unlimited (Hyperbolic)	Omnidirectional		$100,000

*January 1985

of medium-range system, EM waves at such frequencies travel for very long distances, typically limited by transmitter power. Onshore station chains usually are permanent, for use with an appropriate vessel receiver and published hyperbolic lattice charts (Ingham 1975). Achievable accuracies typically are much lower than those of shorter-range systems because long-range systems are designed for general navigation rather than accurate positioning. Satellite navigation systems, which operate at much higher frequencies, afford global coverage at much higher accuracies. Characteristics of selected long-range navigation systems are presented in Table 11.

Loran-C--

Loran, an acronym for long-range navigation, is a pulsed low-frequency electronic navigation system that operates at 90-110 kHz in the hyperbolic mode. Loran-C receivers match cycles to measure time differences between arriving master (M) and secondary (W, X, Y, Z) signals, which are pulse- and phase-coded to enable source identification (Panshin 1979). The microsecond arrival time differences are displayed and can be plotted on a special Loran-C latticed chart as lines-of-position. Fully automatic Loran-C receivers simultaneously process signals from two master-secondary station pairs, displaying LOP information for course tracking.

Range capability varies because Loran-C stations radiate peak powers of 250 kW-2 MW. Due to the use of low frequencies and large baseline distances [i.e., 1,850 km (1,150 mi) or more], Loran-C can provide positional information of reasonable accuracy out to 2,225 km (1,380 mi) with sky waves (Maloney 1978). Range achievable at a particular station is dependent upon transmitter power, receiver sensitivity, noise or interference levels, and signal path losses (Canadian Coast Guard 1981).

At best, the absolute accuracy of Loran-C in normal operating mode over short distances using the ground wave varies from 185 to 460 m (0.11 to 0.29 mi), whereas repeatable accuracy varies from 15 to 90 m (49 to 295 ft) depending on the vessel's location within a given coverage area (Dungan 1979; U.S. Coast Guard 1974). Achieving the short-range accuracies cited

TABLE 11. LONG-RANGE POSITIONING SYSTEM CHARACTERISTICS

SYSTEM	RANGE (km)	FREQUENCY (KHz)	NOMINAL ABSOLUTE ACCURACY (m)	USER CAPABILITY	COST
LORAN-C Multiple Receiver Manufacturers	2500 day 1850 Night	90-110	185-460 15-90 repeatable	Unlimited	$1,000-2,000
LAMBDA DECCA Survey, Ltd. England	400-800	100-200	137 day 730 night	Single 2-range Unlimited-hyperbolic	Call Agent
OMEGA Multiple Receiver Manufacturers	Global	10-14	1800 day 3700 night	Unlimited	$4,000-10,000
VIEWNAV Navigation Sciences Bethesda, MD (301)952-5225	Some Coastal Areas	90-110	±10	Multiple	$40,000 and $2,000 annual fee
TRANSIT Multiple Receiver Manufacturers	Global	150 & 400 MHz	90,1 pass/1 freq. 37-46,1 pass/2 freq. 3-5,Multiple pass and 2 freq.	Unlimited	$2,500-10,000 basic $30,000-45,000 elaborate
GEOSTAR Geostar Corporation Princeton, NJ (609)452-1130	U.S. Land & Coastal Areas	5117-7075 1618-2492	1-7	Unlimited	Transceiver $450 and link Rental $10-30/mo. (Estimated)
NAVSTAR/GPS Mulitple Receiver Manufacturers	Global	1575 MHz 1228 MHz	40,C/A,CEP 8-9,P,CEP	P-Military C/A Commercial Foreign	$10,000-140,000 initial $1,000 eventually
SERIES ISTAC, Inc. Pasadena, CA (818)793-6130	Global	1575 MHz 1228 MHz	< 1 m diff. Mode	Unlimited	$287,000
AEROSERVICE Houston, TX (713)784-5800	Global	1575 MHz 1228 MHz	< 1 m (1/2 hour)	Multiple	$235,000

above requires proper installation, maintenance, and operation of high-quality equipment (Canadian Coast Guard 1981). Higher accuracies can be obtained by operating in a differential mode (i.e., with an onshore supplemental receiver that transmits corrections or offsets to the survey vessel). Available equipment varies from simple receivers and indicators to fully automated receivers with self-tracking capabilities that can interface with a vessel's computer. The cost of a Loran-C receiver, excluding the antenna, varies from less than $1,000 to $2,500-plus.

Although Loran-C frequently is used in Puget Sound for sampling and monitoring, application for barge positioning or monitoring has potential problems. Of particular concern when operating in areas such as Puget Sound are time and spatial variations in the Loran-C signals, and signal interferences that prevent operating in desired survey areas. Inland location [up to 160 km (100 mi)] of Loran-C chains requires overland signal transmission. This results in phase shifts that are difficult to predict. Such shifts can cause an erroneous position location fix. There are also anomalies associated with land-water interfaces and large structures, such as bridges and tall buildings. Crossing-angles also can widely vary from one geographic area to another. In some cases, lines of position almost are parallel, making an accurate fix very difficult. Noise and interference (e.g., from engines and other electronic equipment) also can be disruptive, but most Loran-C receivers are equipped with factory-set or tunable notch filters to minimize such problems.

In an effort to improve navigational capability using the Loran-C system, the U.S. Coast Guard completed a one-time survey of the east and west U.S. coasts in which Loran-C positions were compared with those from a calibrated microwave system. Corrections were obtained for the Defense Mapping Agency nautical charts, whose LOPs were based on theoretical transmission over water paths (Ryan, R., personal communication). These corrections do not include seasonal or diurnal signal effects. The land transmission-path effect (known as the additional secondary phase factor) currently is under evaluation. The results of a recently completed multi-year West Coast Stability Study, which extended from San Diego to Vancouver Island, indicate that the repeatability of Loran-C in Puget Sound is significantly

better than other parts of the country. The annual variation in signals were on the order of 0.2 microseconds (Figure 6). The corresponding 95 percent confidence ellipses and 2 d_{rms} positional repeatabilities at Neah Bay are ±40 m (±131 ft). As the System Area Monitor at Whidbey Island is approached, seasonal stabilities should improve, resulting in improved positional repeatability. Based on the study and the propagation model developed, the Coast Guard can estimate the error ellipse and 2 d_{rms} error circles for disposal site locations within Puget Sound (Slagle, D., personal communication).

Due to differences in the path conditions, measured time differences (i.e., difference in arrival times of two simultaneously transmitted signals) often are different than theoretically predicted. In fact, the deviation varies depending upon the receiver location within the reception area. So-called spatial variation or grid warpage can be removed by applying corrections based on measurements at a nearby site that has been accurately surveyed. Such a procedure was followed by the U.S. Coast Guard during an extensive survey of Puget Sound's major ship traffic lanes. The purpose was to establish accurately located way points to which the vessel can be navigated. Following prescribed turning instructions at a given way point, the vessel proceeds to the next way point, and repeats the procedure until the destination is approached. Given an absolute accuracy requirement of ±40 m (±131 ft), the Coast Guard conducted simultaneous measurements at thousands of locations within the Sound with a Motorola Mini Ranger and a Loran-C receiver. As a result, time differences at geodetically known way points have been published and data for many interim track points have been archived. Thus, for these points, a spatial correction can be made. To maximize the absolute and repeatable accuracy at a given way point requires input of an additional correction factor to compensate for the daily and seasonal signal variations earlier addressed.

To locate some of the disposal sites, way point data can be used to develop a correction for a nearby disposal site based, on interpolation of data from the nearest four way point stations (Gazely, L., personal

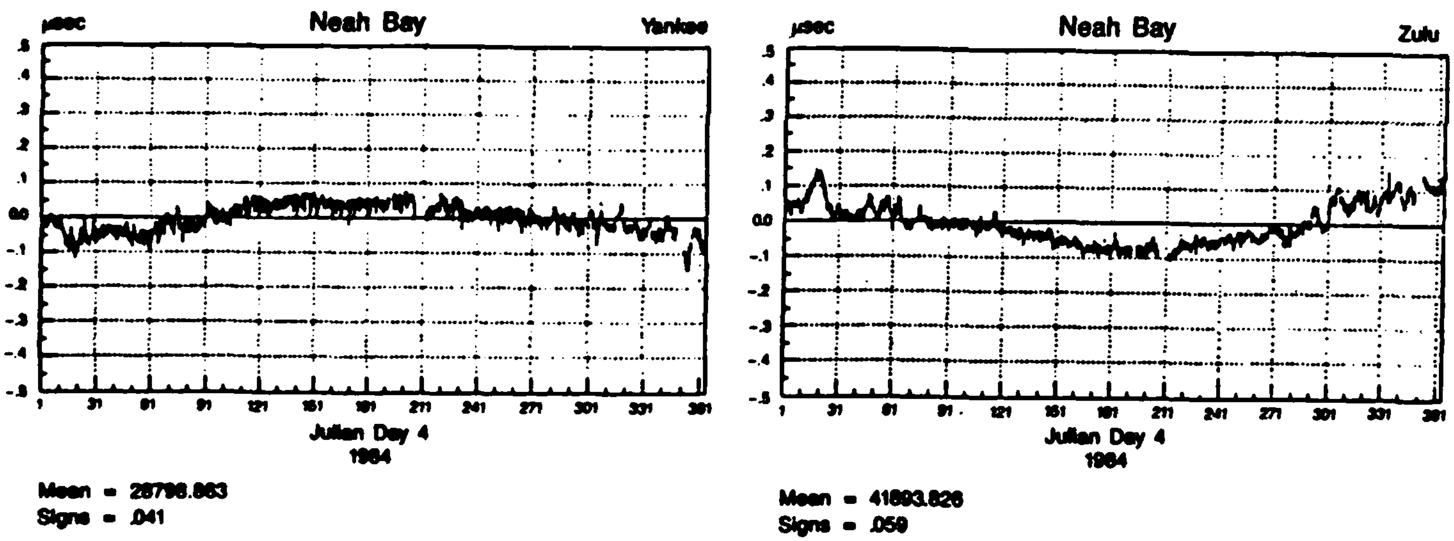


Figure 6. Seasonal variations in Loran-C signals at Neah Bay, Washington 5990.

communication). The accuracy to which the desired time differences can be calculated and the site located is dependent upon distance from the way points or track points to the site location.

Metro completed a similar study with fixes from a microwave system to plot the corresponding Loran-C coordinates within Elliott Bay and surrounding areas. Absolute accuracies within this mapped region are increased to 40-100 m (131-328 ft) with repeatable accuracies substantially better (Sturgill, D., personal communication). Metro and other groups update this Loran-C chart periodically, with a new version expected during the first half of 1986. Because repeatable accuracies of Loran are acceptable for the positioning objectives, calibration of Loran-C positions at disposal sites is a reasonable alternative for long-term projects. It will reduce costs incurred with renting microwave systems (to a single expense). In disposal study sites within or near the calibrated Loran-C stations set up by Metro or the Coast Guard, interpolation from the nearest stations should be adequate for accuracy requirements.

Both temporal and spatial variances from a predicted navigation system grid can substantially be reduced or eliminated by operating in a differential mode (U.S. Department of Defense and U.S. Department of Navigation 1984). A facility (in this case a calibrated Loran-C receiver) may be located at a fixed point within an area of interest. Loran-C signals are observed in real time and compared with signals predicted for the known position. The differences between the observed signal and predicted signal is transmitted to users as a "differential correction" to upgrade the precision and performance of the user's receiver processor. For Loran-C, the serving radius for correction transmission may be up to 320 km (200 mi). The U.S. Coast Guard studied the ability of the differential Loran-C to meet the 8-20 m (26-66 ft) accuracy requirement of U.S. harbors and harbor approaches. For the Seattle area, the Coast Guard Double Range Difference MOD 2 Model predicts that a 20 m (66 ft) 2 d_{rms} absolute position accuracy is feasible when operating in a differential mode (Doughty and May 1985). Tests using Least Squared Error, Alpha-Beta Filter, and Linear Regression Model approaches to predict differential Loran-C time difference offsets indicate that a consistent accuracy within 10 m (33 ft) is not an unreasonable goal for

the particular differential Loran-C system examined on the Thames River (Bruckner 1985).

Radio frequency (RF) interference was evident during the West Coast study, both nearby and within the Loran-C band of 90-110 kHz (Blizard and Slagle 1985). RF interference was noticeably observed at the Tacoma Washington Harbor Monitor Site, and directly affected the Coast Guard's data acquisition and collection. During the 16 months of operation at this site, a significant amount of the data was considered of poor quality, attributable to the intermittent U.S. Navy transmissions at 76.3 kHz. Apparently, the strength of the signal is so strong that it caused the 100 kHz tuned Loran-C coupler to oscillate. Conversations with area users indicated that many other types of receivers also experienced similar problems, thereby limiting the use of Loran-C in the Tacoma area. The extent to which the problem is experienced further away from Tacoma will be receiver-dependent. The U.S. Coast Guard found that use of notch filters in the Hood Canal/Bremerton area eliminated the problem. Identifying the limit of the interference area would require transits away from the source area while attempting to notch out the interference, a task not included in the Coast Guard study.

Other areas with signal interference include relatively small intermittent sources in Elliott Bay and at Seola Beach near Sea-Tac Airport (Figure 7). A large region of northern Puget Sound often is affected, apparently because of another U.S. Navy transmitter. This source precludes rece... from most sets north of Everett (in an area with normally good Loran ...

Two additional sources of interference found in the we... were transmitter switching and chain control effects. The AN... transmitters in the U.S. West Coast Chain (9940) located a... (Master); Middeltown, California (X-Ray), and Sear... are switched every 14 days for routine maintenan... offset for approximately 28 days. The resultant 4... would most likely be detected and app... latitude/longitude conversion algorithm... (5990) would most likely exhibit sim...

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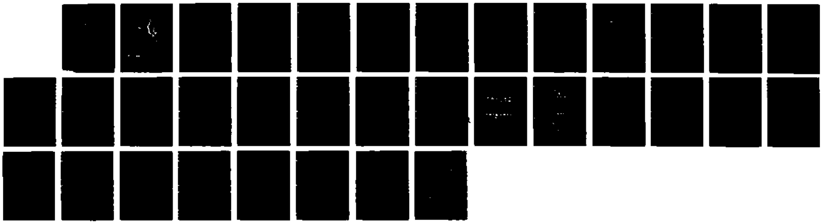
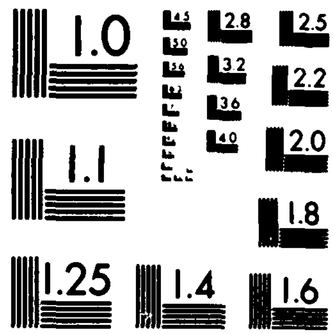




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

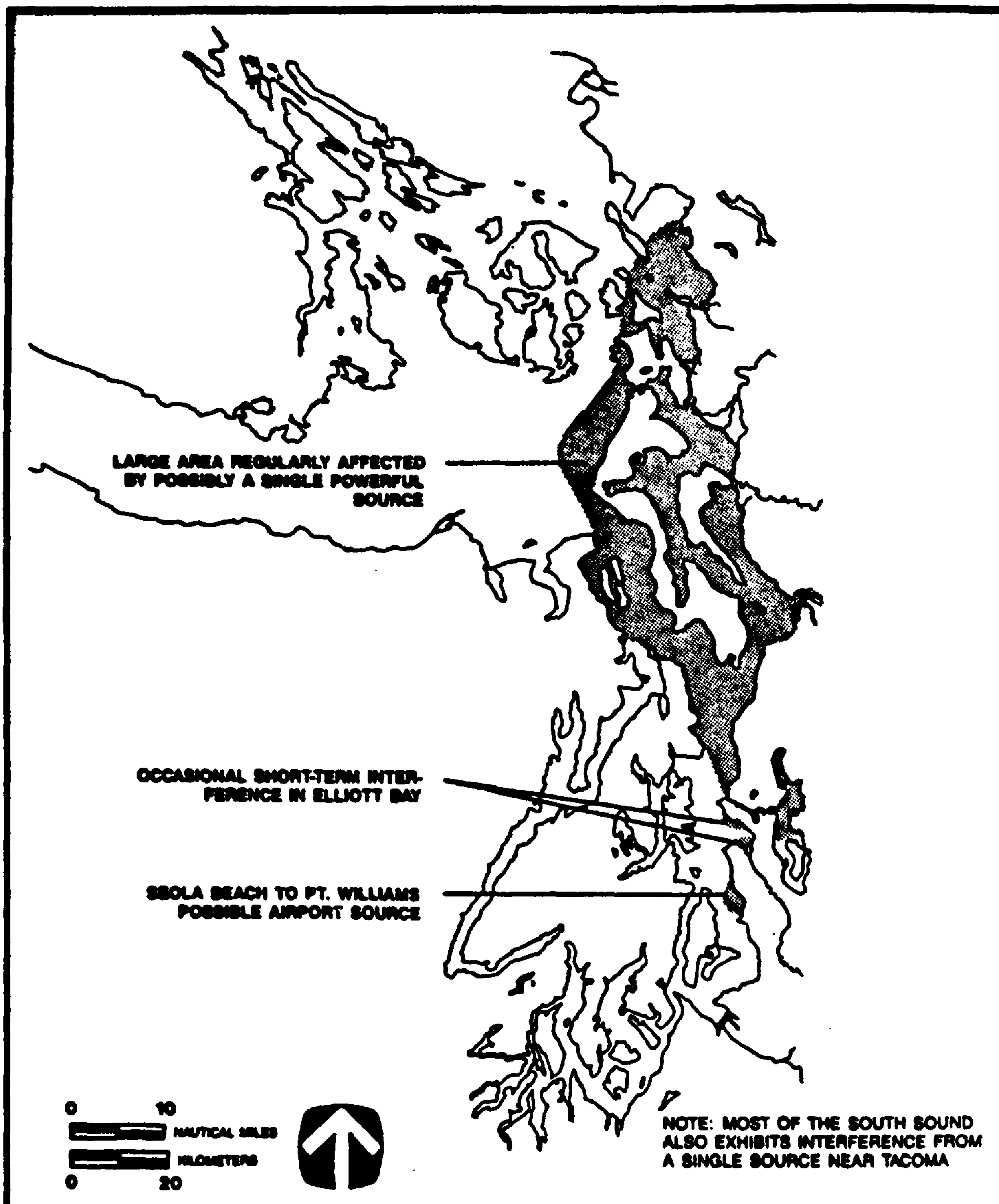


Figure 7. Regions of LORAN-C signal interference in Puget Sound.

Also apparent in the study was the effect of moving an Alpha-1 site receiver that maintains the Control Standard Time Differences. When the 9940 Whiskey A-1 Monitor was moved in December 1984, a positional grid shift of 300 nanoseconds occurred. For a typical gradient of 305 m (1,000 ft) per microsecond, this is equivalent to a 91.4 m (300 ft) change in position. Thus, applying Loran-C in a repeatable mode, the user would have found his "past" position moved by more than 91.4 m (300 ft). In fact, depending on crossing angle, the difference in positions could even be more. Thus, users in the repeatable mode must monitor and compensate any changes in the U.S. West Coast or Canadian Chain (whichever is used) when they occur.

In summary, the accuracies of Loran-C vary depending upon the location. Prior knowledge of the reception at each disposal site is required for an adequate determination of its useability. Achievable accuracies are acceptable to meet the disposal site requirements of a 274 m (900 ft) radius. However, interference will inhibit use of Loran-C at some disposal sites a large percentage of the time, limiting its usefulness. But, because of its relatively low cost, ease of installation/operation, and reliability in known areas over the range of conditions, Loran-C is a candidate system to be considered at some sites.

Viewnav--

To improve upon the positioning accuracy of standard Loran-C receivers, Navigation Sciences has developed Viewnav, an interactive computer system that uses differential Loran-C to position a vessel with a claimed repeatable accuracy of 4.6 m (15 ft). Absolute accuracy of the system is on the order of $\pm$10 m ($\pm$32.8 ft) at the 90 percent confidence level, and $\pm$5 m ($\pm$16.4 ft) at the 20 percent confidence level (Newcomber, K., personal communication). Loran-C offsets are obtained by interrogating onshore monitors established by the company. In addition, a land-based microwave system is used to alibrate a vessel's initial position or track. The system particularly is effective in ports and harbors where large buildings or the land-water interface may alter Loran-C readings.

A distinctive feature of the system is an electronic display of the survey area based on digitized nautical charts. As the vessel moves, its display position moves relative to depth contours and land boundaries. Other waterborne radar images in the area also are indicated. This feature makes it attractive for barge positioning at disposal sites because the tow boat captain can pull into the dumping radius on the screen before releasing.

A full system costs approximately $40,000 with a supplementary annual service fee of $2,000 for chart corrections and equipment maintenance. The base price includes a mainframe Ai-M16 computer with 512KB of main memory, a flexible disk drive with 1MB capacity, and a Winchester hard disk of 10MB capacity. The basic system provides 5MB of chart storage, which equates to approximately 650 charts depending on scale selected. Additional charts can be stored on floppy disks. The manufacturer expects charts and Loran monitors throughout U.S. coastal areas by 1986.

The system could provide improved accuracies over Loran-C, especially in areas of Puget Sound that have not been mapped for Loran. The shore stations require setup time, as does the initial position calibration, making this system more attractive to long-term disposal programs. Loran-C reception limitations again cause limited coverage of the Sound.

Lambda and OMEGA--

These two long-range systems are offshore positioning systems that do not provide adequate accuracies and/or coverage for station positioning within Puget Sound. Interested parties are referred to Tetra Tech (1986) for more information on these systems.

Transit (Navsat)--

The U.S. Navy Navigation Satellite System (originally Project Transit) consists of a group of satellites in 106-min circular polar orbits at altitudes of approximately 1,411 km (877 mi). The system also includes ground tracking stations, a computing center, an injection station, U.S. Naval Observatory

time signals, and vessel receivers and computers. Positional measurements are based on the Doppler frequency shift that occurs when the relative distance between the satellite transmitter and vessel receiver changes (i.e., frequency increase upon closure and frequency decrease upon separation). Provided the satellite orbits are accurately known, it is possible to locate the receiver. The nature of the Doppler shift depends upon the exact location of the receiver relative to the satellite path (Maloney 1978). The system operates at frequencies of 150 and 400 MHz so that ionspheric corrections can be made through signal comparison techniques. The vessel's position is determined based on "known" orbital positions during satellite passage and measured frequency shifts.

As originally designed, at least one satellite would be within line-of-site every 35 to 100 min. However, at U.S. East and West Coast latitudes, the acceptable fix window is approximately every 90 min (Driscoll, C., personal communication). This is caused, in part, by the requirement that a satellite's maximum altitude be between 15° and 75° before a fix is considered valid. Another problem occurs when two satellites being tracked have approximately the same closest approach, whereupon it becomes difficult to know which one is monitored. Typically, each satellite provides four fixes a day on two successive orbits spaced by 12 h. Because one satellite currently is inoperative and another has weak batteries, it may take longer (e.g., several hours at the equator) to gain a valid fix (Booda 1984). A static position fix with Transit using singlechannel equipment can be made with an accuracy of approximately 90 m (295 ft). Dual-channel receivers improve single-pass accuracy to 37-46 m (121-151 ft) (Hoeber 1981; Maloney 1978). With multiple passes, an rms accuracy of 3-5 m (9.8-16.4 ft) is claimed by some equipment manufacturers.

Transit receiver costs range from $2,500 to $10,000 for basic single frequency units (Murphy, W., personal communication). More elaborate multiple-channel systems, sometimes in combination with OMEGA, range in cost from $30,000 to $52,000 (Jolly, J., personal communication; Driscoll, C., personal communication).

Use of the Transit system generally is not appropriate for disposal programs because the users need to occupy the disposal site for a relatively short time. A fix must be based on a single pass. With satellite passes at 1-h or 2-h intervals, multiple-pass data acquisition is impractical. Therefore, only the best single-pass accuracy of 37-46 m (121-151 ft) can be achieved, which is adequate for positioning requirements. However, the largest disadvantage of the system still is the time constraint between fixes, which does not make it appropriate for surveys using expensive ship time.

GEOSTAR--

GEOSTAR is a pulse radio transmission system. Recently approved by the FCC, it will provide satellite information for positions within the continental U.S. and its coastal waters by 1987. Three geosynchronous satellites (and a fourth as backup) will orbit the earth at 37,000 km (22,991 mi) at 70°, 100°, and 130° W longitude. System components include transceivers, satellites, and computers at a ground center. The links between the ground station and the satellites will operate at 5,117-5,183 MHz and 6,533 MHz, while user-satellite links will be at 1,618 and 2,492 MHz (Whalen 1984). Should a satellite fail, the backup would be moved into a proper orbit by telemetry command from the ground computer facility.

The user will send a command through the transceiver, which relays the message through the satellites to a central computer at the ground center, reportedly in less than 1 sec. The signal-arrival times from each satellite are used by the ground computer to calculate the position of the specially coded transceiver. The information is then transmitted back to the satellites and relayed back to the transceiver in a similar amount of time.

GEOSTAR will enable a typical single-shot positioning error of 2-7 m (6-23 ft), according to the developer. When needed, accuracies down to 1 m (3.3 ft) reportedly can be achieved with two-way interaction, signal analysis, and averaging. Users at a known elevation (e.g., sea level) will have greater accuracy due to much smaller geometrical dilution of

precision where only two (rather than three) coordinates are required. Continuous operations in a differential mode also should enable correction inputs for such errors as ionospheric delays, satellite position drift, and drifts in satellite electronic delays.

System designers estimate that, when operable, the cost of a basic hand-held transceiver with a typewriter keyboard and LCD display will be less than $1,000. A monthly service charge of $10 to $30 also is anticipated (Howarth, C., personal communication). At publication, FCC had not completed its review of GEOSTAR Corporation's application for use of the requested frequencies. Candidate users are urged to confirm FCC approval, verify the latest satellite/ground station operating schedule, and obtain further information on transceiver availability.

Navstar GPS--

The Navstar Global Positioning System (GPS) is a second-generation satellite navigation system currently under development by the U.S. Department of Defense. Its purpose is to provide precise, continuous, worldwide, all-weather, three-dimensional navigation for land, sea, and air applications. Under current plans, 18 satellites will be launched into three co-planar orbits 120° apart to provide continuous transmission of time, three-dimensional position, and velocity messages to system users. The GPS satellites transmit at 1,227.6 MHz and 1,575.4 MHz to permit the measurement and correction of ionospheric refraction error. Five developmental satellites currently are in orbit, providing approximately 4 h of coverage twice daily, separated by a 12-h period. Continuous two-dimensional positioning information should be available with 12 satellites by February, 1988, and three-dimensional coverage is projected for late-1988 or early-1989 (DeGroot, L., personal communication; Stansell 1984). The system consists of the satellites in 12-h, 20,200-km (12,552-mi) orbits, a U.S. master control station, several monitoring stations, and small, lightweight, relatively inexpensive receivers. Signals received from any four Navstar satellites are demodulated, time-correlated, and processed to obtain precise position information.

Two levels of positioning accuracy are achievable with the Navstar GPS system. The lower level is obtained from the Standard Position Service (SPS) using the coarse acquisition or "C/A code." When the system becomes fully operational, navigational accuracy from these signals should be approximately 100 m (328 ft) two-dimensional rms, or a circular probable error (CEP) of 40 m (131 ft) (Montgomery, B., personal communication). More accuracy can be achieved using the Precise Positioning Service (PPS) or "P-code" (i.e., 8-9 m two-dimensional CEP). Additional positioning accuracy can be achieved by operating in a differential mode, in which receivers on a vessel and at an onshore location simultaneously receive the satellite signals. The onshore receiver is calibrated. Bias corrections based on signals received at the fixed station are transmitted to the mobile receiver. These area-specific corrections yield more accurate positional determinations. With differential GPS, a two-dimensional position should be definable within a range of 2-5 m (6.6-16.4 ft) (Montgomery 1984; Stansell 1984).

Due to the present lack of full-time coverage, both SPS and PPS are available to military and civilian users. However, the government intends to encrypt the P-codes, allowing use only by the military and other authorized users [e.g., National Ocean Industries Association (NOIA) members]. It would appear that general users will be limited to C/A code equipment. Accuracies obtained from the C/A code are adequate for disposal site positioning requirements.

Because the GPS system is in a developmental stage, cost estimates for the equipment are difficult to make. Several major equipment manufacturers are in the process of designing receivers with varying capabilities, and a limited number of models now are available. Some manufacturers envision that receivers with 100-m (328-ft) accuracy will cost less than $500 when mass produced (e.g., for automobiles). At the other extreme, for $140,000 Texas Instruments sells the TI4100 Navstar Navigator, said to be capable of slow dynamic positioning within a few meters, speed within tenths of a knot, and time to the microsecond (Montgomery 1984; St. Pierre, R., personal communication). Motorola anticipates that the initial cost of two stations needed to operate in the differential mode will be in the $100,000-range (Sheard, S., personal communication). Magnavox has a five-channel T-Set

GPS Navigator, with real time differential GPS operation as a planned option. A two-unit system, excluding communications link, costs approximately $100,000 (Driscoll, C., personal communication). Rockwell International sells a prototype C/A code receiver for $17,500 and anticipates that GPS receivers will cost less than $10,000 by 1988 (DeGroot, L., personal communication). Tracor expects initial models to sell for less than $10,000, falling to around $1,000 in 3-5 yr (Murphy, W., personal communication).

SERIES and Aero Service GPS--

These two satellite navigation systems do not offer any positioning or monitoring advantages over those discussed. The higher cost of these systems offers no clear advantage in meeting program objectives, and it eliminates these systems from consideration.

RANGE-AZIMUTH SYSTEMS

A number of hybrid positioning systems combine positional data from various sources to obtain fixes. Such methods usually involve the intersection of a visual line-of-position with an electronic line-of-position (Umbach 1976). Visual data may be in the form of sextant angles or theodolite azimuths. Electronic positional data are normally obtained from a microwave system.

Of particular interest for barge disposal and site monitoring programs, are dynamic positioning methods that require only a single shore station and that use the simultaneous measurement of angle from a known direction and range to the vessel. This range-azimuth method has the advantage of circular coverage around the shore station (Figure 8). A single station minimizes logistical requirements and geometric limitations. Line-of-position intersections are the ideal 90° everywhere within the coverage area. Growth in the error ellipse is due only to distance from the shore station because of its independence of the absolute azimuth angle. Accuracy improves as range decreases, even fairly close to the shore station, and only one unobstructed line-of-sight is needed. However, such systems allow only a single

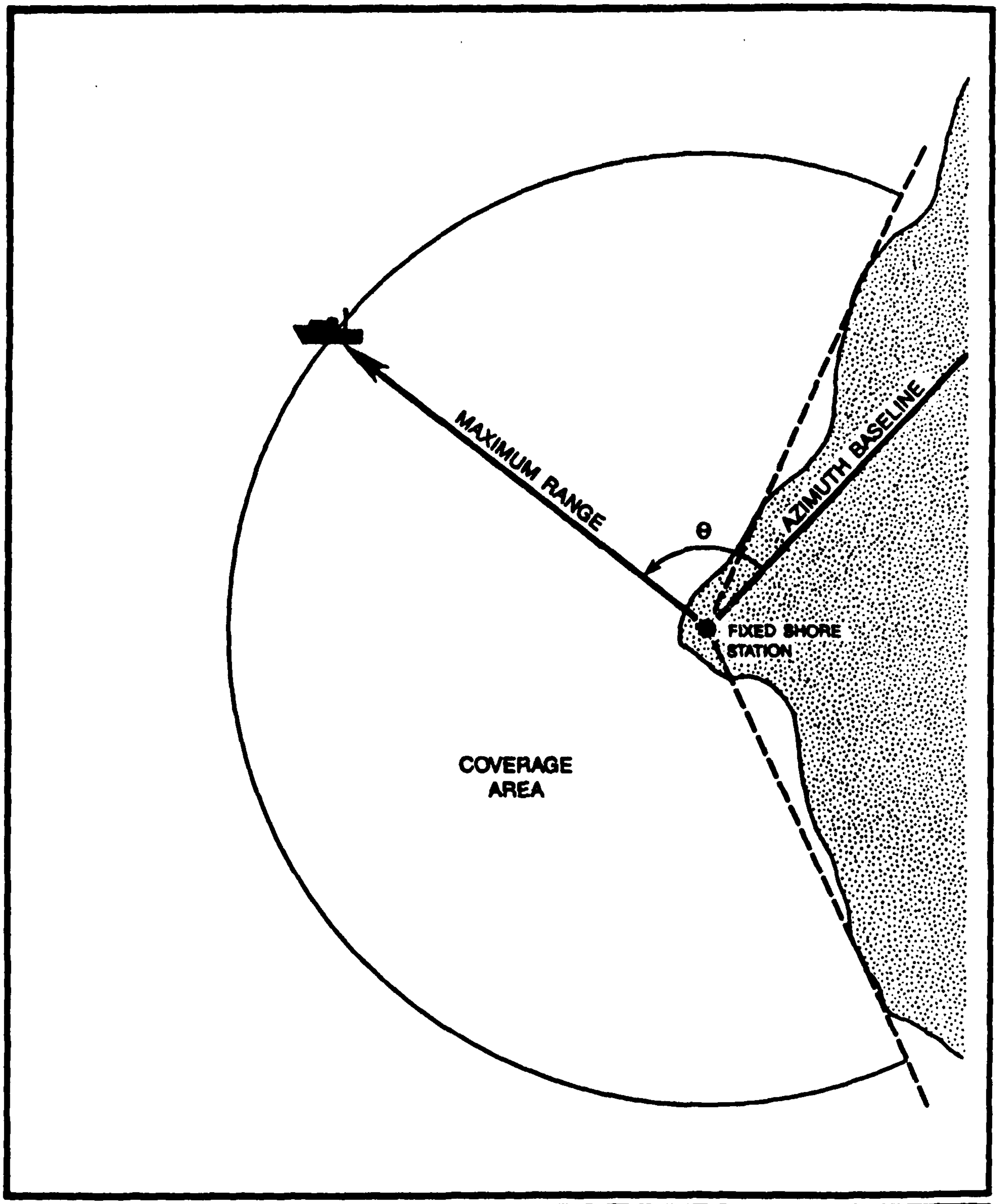


Figure 8. Range-azimuth positioning system area of coverage.

user and would have to be set up on the appropriate tug for any disposal operation.

Characteristics of three representative systems are summarized in Table 12. Two have fully automatic shore stations, requiring attendance only during setup and alignment. The third requires an onshore operator at all times. For multiple-day surveys, an automatic station eliminates the tedium of continuously tracking the survey vessel. The methods offer much greater flexibility than range-range or hyperbolic methods with multiple onshore stations. Where positioning requirements extend into ports, estuaries, or up rivers, the single-station systems offer distinct advantages in covering restricted or congested survey areas and in establishing an unobstructed signal path. Each system is distinctive in either its operating medium (optical, microwave, laser) and/or procedure (i.e., manual or automatic tracking). The added costs of these systems over standard microwave systems may be justified because of the potential as a monitoring tool or where the method also can be used for onshore work during non-dumping periods.

AZTRAC

The ODOM Offshore Survey AZTRAC is a semiautomated optical angle-measuring and transmitting system which can be used in conjunction with an independent distance-measuring system to position a vessel. The AZTRAC system consists of a modified Wild T16 theodolite, an onshore transmitter, and a vessel receiver. The theodolite has an infinite tangent drive and provides information in a digital format. Typically, the separate distance-measuring system consists of a microwave master receiver on the vessel and a remote unit transmitter located at the theodolite.

For a survey, the AZTRAC theodolite and transmitter are set up at a known position and the theodolite is zeroed on a known azimuth line of backsight. The theodolite operator sights and tracks the survey vessel's ranging antenna or transponder. As the vessel moves, the microwave ranging system continuously measures distance between the shore station and the vessel. The tracking motion produces pulses that are decoded by the AZTRAC transmitter and displayed to the theodolite operator as the angle to the

TABLE 12. RANGE-AZIMUTH POSITIONING SYSTEM CHARACTERISTICS

SYSTEMS	FREQUENCY	RANGE	NOMINAL ACCURACY AZIMUTH	NOMINAL ACCURACY RANGE	NOMINAL ACCURACY POSITION	COST
AZTRAC Odom Offshore Surveys Baton Rouge, Louisiana (504)769-3051	Optical and microwave (typical)	Visible	0.01^{o}	Both depend on accuracy of ranging system used		$22,500 plus ranging system cost cost
POLARFIX Krupp Atlas-Elektronik Webster, Texas (713)338-6631	Laser (904 nm) UHF Telemetry (406-470 MHz)	5000 m	0.01^{o}	±0.1m±0.1m/km	±0.1m±0.2m/km	$100,000
ARTEMIS Andrews Hydrographics Houston, Texas (713)558-2236	9.2-9.3 GHz	10-1400 m or 200-30,000 m	0.03^{o}	0.5 m short 1.5 m long	Not stated	$70,000 to $75,000

vessel from the reference azimuth line. The angle also is converted to BCD serial format and is used to activate the transmitter, which sends the information to the survey vessel. The AZTRAC receiver converts the angle information to parallel format and displays it for manual recording. It simultaneously outputs the angle as serial data for automated recording or processing by any available on-board computer or plotting system.

AZTRAC is designed to operate with most microwave ranging systems. Two AZTRAC units working in an azimuth-azimuth mode can provide positioning in survey areas where reflections from metal structures or electrical noise from radar and other transmitters limit use of microwave ranging. The Wild T16 theodolite has a 30X magnification, 27-m (89-ft) field of view at 1,000 m (3,280 ft), and an angular resolution of 0.01° (36 arc sec); at a distance of 5 km (3.1 mi), this corresponds to an absolute arc length error of 0.9 m (3.0 ft).

The National Ocean Survey recently examined range-azimuth positioning of a vessel moving at a nominal speed of 6 kn (11.1 km/h) at ranges of up to 3,000 m (9,842 ft). Instruments included a Wild T2 theodolite, from which angles were manually recorded onshore, and the AZTRAC, whose angles were recorded on the vessel. Pointing errors (68 percent probability) of these two instruments were found to be approximately 1.3 m (4.3 ft), independent of range when standard deviations of right and left movement data were pooled (Waltz 1984).

The theodolite was sited on a white Del Norte Trisponder transponder on the moving vessel. Visibility was good during the 2-day survey (off Monterey, CA), with calm mornings giving way to afternoon winds of 15 kn and 0.6-0.9 m (2-3 ft) seas. Range could have been extended much farther under such conditions, particularly if color had been added to the vessel target (Waltz, D.A., personal communication). U.S. Army Corps of Engineer users confirmed the effectiveness and reliability of the AZTRAC method in conjunction with several different microwave ranging systems (Ard, R., personal communication). The method also has proven effective in port and harbor surveys when it was impossible to achieve optimal shore station geometry for range-range or hyperbolic operation.

The current cost of the AZTRAC alone is $22,500 (Apsey, B., personal communication). A system consisting of the AZTRAC, a Motorola Falcon 484 with one reference station (approximately $32,000), and an interface unit ($10,000) would cost $64,500. Thus, provided the required range is achievable under anticipated visibility conditions, the additional versatility of the AZTRAC can be realized for $25,000 above the $39,300 cost of a two-station Falcon 484 range-range microwave method.

POLARFIX

POLARFIX is a dynamic range-azimuth positioning system by Krupp Atlas-Elektronik. The system uses a scanning (30° horizontal) pulsed laser beam from a single, fixed, onshore tracking station to follow the survey vessel (up to 10°/sec) and to transmit range and angle information via telemetry link. The system incorporates a fully automated onshore tracking station, which requires no attendance beyond initial station setup and azimuth referencing. The shore station can locate the mast-mounted prism reflectors, follow the vessel, and, if necessary, relocate the vessel by performing a routine search pattern based on a record of tracking history. The shore tracking station consists of a laser-sensing head mounted on a conventional survey tripod, linked by cable to an integrated control unit that houses data control, transmission, and telemetry transceiver equipment. An integral control unit (including a display and a second telemetry receiver), keyboard terminal, printer, telemetry antenna, and prism reflector assembly are on-board the vessel. In addition to navigational capability, this control unit would provide a record of the vessel's disposal run.

Under clear operating conditions, a 3-km (1.9-mi) range using a Class I laser or a 5-km (3.1-mi) range using a Class IIIa laser may be selected. In foggy weather, range is said to be 1.5 times visible range, due to use of the pulsed infrared laser. Maximum range achievable varies with the prism assembly used to reflect the tracking station's laser beam. Single-, dual-, and triple-ring omnidirectional prism assemblies can be stacked on the vessel antenna. For average weather conditions, a two-prism assembly (each with five reflectors) gives approximately 3.5 km (2.2 mi) of range.

This can be extended to approximately 5.0 km (3.1 mi) with the addition of more assemblies. Although a 5 km (3.1 mi) distance from shore will cover most of the Sound, this does add limitations to range in some areas.

Range accuracy is reported as 0.1 m ±0.1 m/km (0.3 ft ±0.5 ft/mi) of measured range. Azimuth accuracy is said to be 0.01° or better. The resulting positional accuracy at 1, 3, and 5 km (0.6, 1.9, and 3.1 mi) is approximately 0.3, 0.6, and 1.0 m (1, 2, 3.2 ft), respectively. The positional algorithm given is ±0.1 m ±0.2 m/km (±0.3 ft ±1.1 ft/mi). Current cost of the system is $100,000 (Guillory, J., personal communication).

ARTEMIS

The ARTEMIS by the Christiaan Huygenslabortorium (Holland) is a distance-bearing type of microwave positioning method capable of measurements at ranges of 10 m (32.8 ft) to 30 km (18.6 mi), and angles from 0° to 360° from a single fixed shore station. Accuracies at the two-sigma or 95 percent level are given as ±1.5 m (4.9 ft) distance, and ±0.03° azimuth, equivalent to ±0.5 m/km (2.6 ft/mi).

Angle measurements are based on automatic tracking antennas on the vessel and at the shore station. Once locked, the two antennae move always pointing towards each other. A maximum combined tracking speed of 3°/sec is allowable to achieve the specified angle error. The direction of the fixed station antenna is accurately measured with a precision shaft coder, which is mechanically coupled to the main shaft of the antenna. Measured angle data are transferred to the mobile station via the established continuous microwave channel. The same microwave link is used to measure distance by controlled interruption of the microwave signal. Both angle and distance usually are displayed on the Mobile Control Data Unit, although readout at the shore station also is feasible. The microwave link also is used for voice communication between the two stations without disturbing the data being transmitted.

The vessel's positioning equipment consists of the Mobile Control Data Unit (MCDU), a Mobile Antenna Unit (MAU), the antenna, cables, a telephone

handset, and a speaker. The shore station consists of a Fix Antenna Unit (FAU), Fix Control Data Unit (FCDU), an antenna, cables, a telephone handset, a speaker, and a telescope for initial directional alignment. The shore station requires attendance only for setup, referencing, and periodic battery checks. The bearing is electronically referenced to a geodetic grid by siting the unit in a known reference direction and manually adjusting the observed direction readout to the correct value.

Limiting factors (common to all microwave systems) include radio line-of-site conditions (obstacle-free for optimum performance) and multipath interference due to reflections from the sea surface. The latter can be reduced by proper adjustment of antenna heights. Where disposal site area traffic is heavy, signal interruptions could unlock the two tracking antennae. Manual relocking by a shore station attendant or automatic relocking using autosearch, an option available at added cost, would then be necessary. Although signals generally are unaffected by rain and fog, there is some range reduction during heavy rains or snowfalls.

The present system costs $70,000-$75,000, depending on the options selected (Coupe, C., personal communication). The system may be rented from Andrews Hydrographics, Inc. (Houston, Texas) for approximately $850 per day.

DEDICATED MONITORING SYSTEMS

A number of position monitoring systems have been developed to keep track of various vessels or vehicles that handle restricted substances. Most of these methods are based on Loran-C navigational systems, but can be modified to use GPS or GEOSTAR navigation as these new satellite systems become fully operational. All of these methods are capable of remote recording of the vessel's track to and from a disposal site. Most even allow real time monitoring of the dumping operations. The advantages of these systems for monitoring include the absence of remote land-based stations that are hard to protect, "third-party" centralized monitoring for all disposal sites, and multiple vessel capability. The characteristics of these systems are presented in Table 13.

TABLE 13. VESSEL POSITION MONITORING SYSTEM CHARACTERISTICS

System	Positioning Determination	Position Resolution (m)	Real Time Monitoring	Permanent Records	Cost Estimate
Ocean Dumping Surveillance System U.S. Coast Guard Washington, D.C. (202) 426-1040	Loran-C	40-100	yes	yes	$10,000/remote base varies
Pathlink Technology Projects, Ltd. Pascor Division Tempe, Arizona (602) 968-2818	Loran-C	40-100	capable	yes	$30,000-$40,000
Vehicle Tracking System II Morrow, Inc. Salem, Oregon (503) 581-8101	Loran-C	40-100	yes	yes	$25,000-$35,000
CORT 500 Racal Megapulse Bedford, Massachusetts (617) 275-2010	Loran-C	40-100	yes	yes	$11,000/remote base varies
Tracker METS, Inc. Pompano Beach, Florida (305) 979-5404	Loran-C	40-100	yes	yes	$30,000 and up
Vessel Traffic Service Radar U.S. Coast Guard Seattle, Washington (206) 442-4124	Variable range radar	20-50 range 1° bearing	only	written by observer	none

Another method that can be used to monitor disposal site use is the U.S. Coast Guard Vessel Traffic Service Radar. This method is based upon the variable range radar method used by the Coast Guard to monitor vessel traffic in Puget Sound. Barges are informed if they are within disposal site boundaries. System characteristics also are listed in Table 13. This method does not cover all existing disposal sites within Puget Sound.

Ocean Dumping Surveillance System

The U.S. Coast Guard has developed a pilot monitoring system that uses Loran-C to continuously track vessels within a harbor, and in transit to and from a dump site (Doughty et al. 1985). Development was prompted by pressure to move dumping areas farther from shore (e.g., to the 106 Mile Site off New York), which would significantly raise the cost and time to monitor operations for regulation compliance. Two basic approaches were examined in developing the system. One was the recording of all information onto magnetic tape, disk, bubble memory, or other mass media aboard the dumping vessel for subsequent processing and review. The second approach involved frequent transmission of information to a shore station for immediate processing and display. The latter approach was selected to enable immediate detection of violations, stopping of a discharge in the wrong location (thereby limiting environmental damage), and a greater chance of apprehending violators. In addition, the station operator automatically is alerted to equipment failures or attempts to tamper with the system. A design constraint is that the on-board remote package cost less than $10,000 when purchased in quantity. Also, the system was to minimize the workload on watchstanders at the base station and operation centers where dumping reports must be prepared.

The pilot system developed for the New York area uses one base station and four remotes. The base station consists of a Hewlet-Packard HP-1000 minicomputer system with 1 megabyte of random access memory, 16.5 megabytes of hard disk data storage, two HP-150 Touch Screen desktop computers, two printers, a low-band (40 MHz) VHF tranceiver, and an Advanced Electronic

Applications Inc. model PKT-1 packet radio network controller that conforms to the ISO standard multi-tasking operating system.

The remote unit consists of a small computer, a RAYNAV 750 Loran-C receiver, a packet radio controller, a VHF-FM transmitter, receiver, a 40-watt power amplifier, three pressure transducers, and a battery-backed power supply. The computer is a single-board with STD bus and an 8085 microprocessor. An eight channel analog-to-digital converter card, a two-channel USART (two RS-232 ports), and a 64 kilobyte CMOS memory card also reside on the bus. The large CMOS memory enables the remote to store up to 4000 samples (about 7 days) of data during periods when radio or satellite communication is unreliable. The software was developed, compiled, and transferred to 8085 machine code and "burned into" PROM, making it nonvolatile during periods of power loss.

After evaluating many techniques for sensing actual dumping (e.g., dump door switches to flow rate sensors), a pressure transducer was selected for simplicity, reliability, security, and applicability for all sludge vessels. The only problem with such an indicator is its susceptibility to fouling. Tests with anti-fouling paint additives are now being conducted by the U.S. Coast Guard.

Every 2 min, the remote's computer scans all peripheral devices, obtaining date and time, position information, Loran-C receiver status, pressure readings from the three pressure transducers, and "housekeeping" data regarding battery levels and tamperings with the remote enclosure, or the pressure sensors and their cables. Also, should the vessel enter any of the pre-programmed forbidden zones (e.g., containing facilities that dispose of materials the vessel is not permitted to carry or dump) for more than a preset time interval, the remote sets a flag read by the base station on its next interrogation. Pressure transducers are read at the rate of 3 samples per sec; one hundred samples are then averaged to determine draft indication.

A base station packet radio controller interrogates each remote unit based on polling intervals shown in Table 14. If a remote unit does not respond, it is interrogated a second time. If this fails, the base station can switch to an alternate communication channel or another base station transceiver located near a different portion of the dump site route. The base station can dial transceivers over the commercial telephone network or use the built-in repeater functions of the packet radio controllers. If communication is unsuccessful through all alternate channels, the base station moves to the next remote unit and records a "COMMSLOST" indication in the status data set of the database. This also appears on the VESSEL MENU display screen for the watchstander.

The Watchstander Display and Touch-Terminal consists of approximately 12,000 lines of PASCAL code. The programs interpret the information gathered by the Data Collection and Storage Program, and put it into a format easily understood by people with little technical training or computer experience. All watchstander interaction is through the touch-screen of an HP-150 personal computer operated on a terminal under the control of the HP-1000 minicomputer. The system uses a series of touch-activated display screens, such as in Figure 9. When a particular vessel name is touched on the VESSEL MENU, the detailed VESSEL STATUS (Figure 10) is displayed. Touching any of the commands displayed in the bottom row of the VESSEL MENU screen causes the system to request a selection of a vessel for that command. Upon doing so, the system produces the requested data such as VESSEL HISTORY or VESSEL SPECIFICATION (Figure 10). Information presented on each of display screens is summarized in Table 15.

Loran-C was selected to provide vessel location data because its accuracy was acceptable at 40 m (131 ft) or better for the 106 Mile New York Dump Site area, the data sets are readily available, reliable and inexpensive, and the Loran-C was proven acceptable as evidence in law enforcement proceedings. The Ocean Dumping Surveillance System is developed to a point that it could be purchased with a design specification.

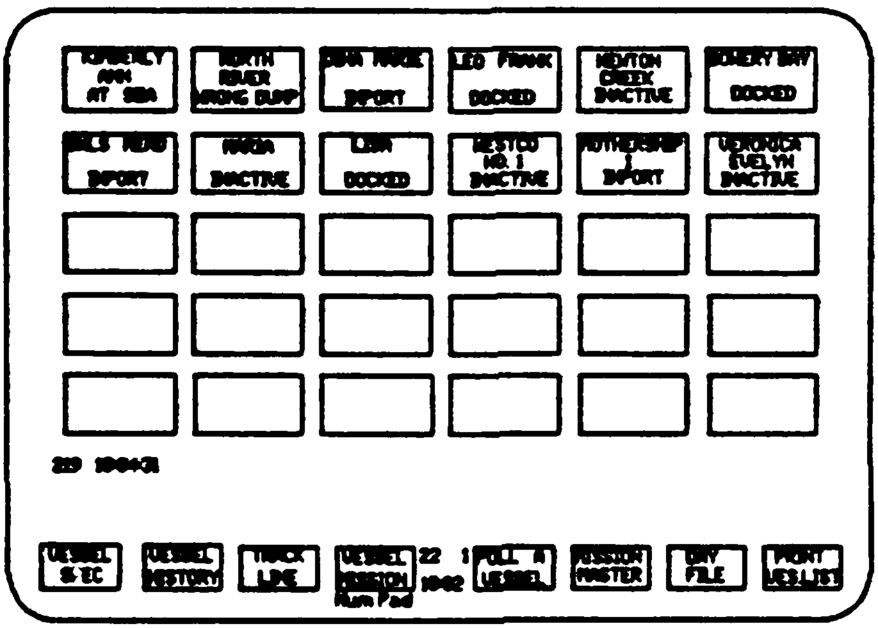
Although this system has been designed for use with Loran-C, it also could use GPS or other navigational signals. It is conceivable that, as

TABLE 14. POLLING INTERVALS

Item	Interval	Samples
Inactive	60 min	1
Docked	60 min	1
Underway in port	20 min	1
Underway at sea	20 min	1
Transferring cargo	10 min	5
Near dump zone	10 min	5
Dumping	10 min	5
Dumping out of zone[a]	10 min	5
In forbidden zone	10 min	5

[a] Gets last 10 updates then switches to this interval.

NOTE: A sample is taken every 2 min by each remote.



VESSEL MENU

Figure 9. Display screen and menu for the Ocean Dumping Surveillance System.

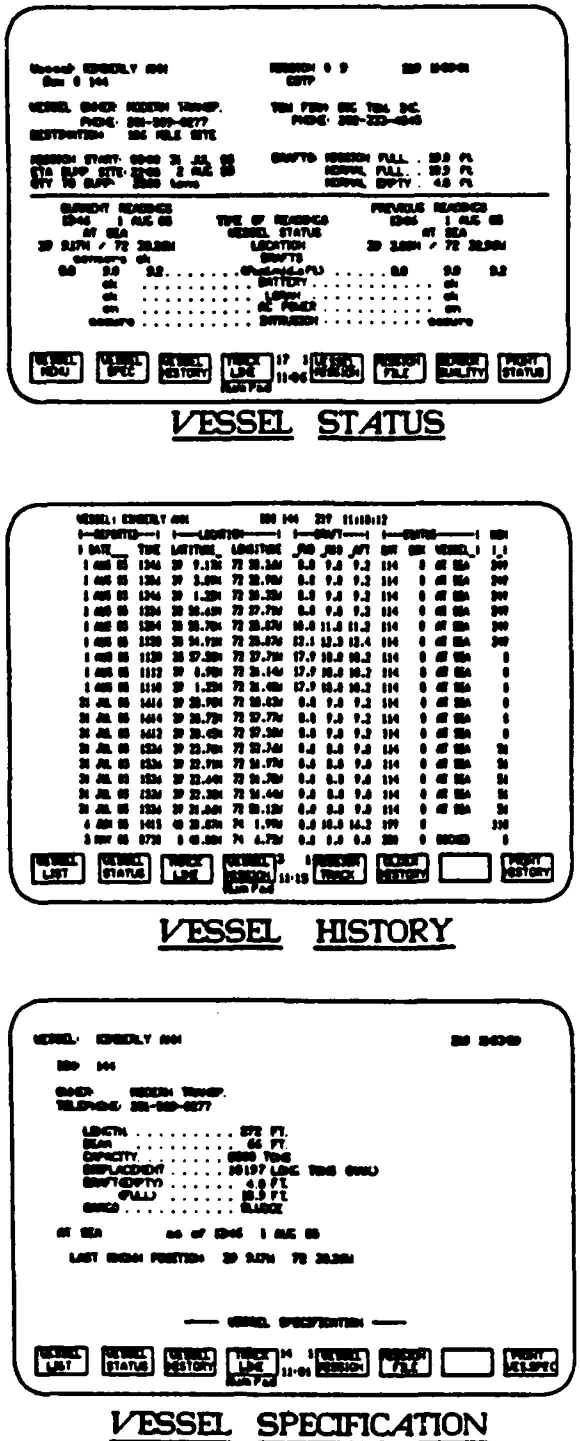


Figure 10. Vessel specific information from the Ocean Dumping Surveillance System.

TABLE 15. SUMMARY OF DISPLAY SCREEN INFORMATION

Vessel Menu	All vessels in the database and their current status. Any change in status, including a violation will cause the appropriate vessel's status indication to blink and an audible alarm to sound.
Vessel Status	Current status of a specified vessel, mission data, previous transmission of vessel status. Vessel information that normally changes (e.g., position or draft).
Vessel Specification	Non-changing specific vessel information.
Vessel History	All entries in the history data set for a specified vessel.
Vessel Trackline	A representation of the harbor area, with the vessel location for the last 70 entries. Dots for location, asterisk for dumping.
Mission Track	Same as Trackline, except locations are displayed only for the designated mission.
Dumpsite Track	Similar to Trackline except the area shown is only that of the dumpsite and surrounding water.
Vessel Mission	Advance information required of vessel operators and entered by watchstander (e.g., notice of intent to execute a mission, ETA at the dump site, cargo description including volume and constituents).
Mission File	All historic entries relating to a specified mission along with mission start time, ETA at dump site and mission end time.
Draft Sensor Quality	Selects which of the multiple draft sensors will be used when the vessel's draft is determined.
Mission Master File	List of all mission's currently held in the mission data set.

the number of monitored vessels, vehicles, and aircraft expands, a dedicated satellite system could be used to provide simultaneous monitoring of a wide variety of waste management or other regulated activities at a reasonable cost.

Pathlink System

The Pathlink System is an electronic unit used to permanently record position, time, and event information for a vessel or, using an optional telemetry link, to provide the same data in a real time mode. The system consists of a portable Path Recorder that is placed on the monitored vessel, and a shore-based Path Analyzer for data retrieval, analysis, and storage. The Path Recorder consists of a II Morrow Apollo Loran-C receiver, a bubble cassette recorder, a calendar/clock, and four binary switches for recording on-off sensor data, all in a locking tamper-proof enclosure. Additional channels can be optionally provided to record analog signals from up to 16 sensors. During normal operation, a magnetic bubble cassette is placed into the recorder (prior to beginning a transect) to obtain a permanent record of the ship's track and other input variables such as speed, draft, and position. The 128 kilobyte cassette is configured to store 6,400 records. This equates to more than 5 h with "three-second" samples (aircraft tracking) or 106 h with a "one-minute" sample time. Sampling rate can be modified to meet a specific application.

The Path Analyzer includes an IBM PC/XT computer, 10 megabyte hard disk, a Bubble Memory Cassette Module (reader), monitor, printer, and standard software for data logging and analysis. Optionally, the customer's IBM compatible computer can be used. The display screen usually depicts the track of the vessel upon playback of the bubble pack. However, the display format can be tailored to the users needs. If real time monitoring of the vessel is required, a UHF or VHF transmitter for the ship and RF telemetry receiver for the control station can be provided. The normal transmission power of 2 watts can be increased by up to 100 watts using an external power amplifier. Alternately, the vessel's SSB or HF transmitter link to shore can be used. Operating in such a mode permits several vessels with path recorders to be followed simultaneously, with information presented

on the Path Analyzer screen in formats similar to that discussed for the U.S. Coast Guard's Ocean Dumping Surveillance System.

The major differences in the Pathlink and Ocean Dumping Surveillance System include Pathlink's smaller size (33 lb remote unit), simplicity in initiating operation of the remote unit (2 switches), existence of a permanent record for litigation and/or documentation (regardless of communication link or shore-based equipment failures), continuous transmission (e.g., at 3 sec to 1.5 min intervals), and information recording to shore rather than storage of data on the vessel with periodic burst transmissions upon inquiry. Software for notification of when a vessel enters restricted areas or desirable ones, such as the boundary of approved dumping zone, can be provided.

Advertised cost of the PR 2000 Path Recorder is $13,395 and the PA 3000 Path Analyzer is $16,550, with government discounts available. The vessel-to-shore telemetry transmitter is available for $1,380, and telemetry receiver cost is $1,946. Customer supplied antennas are estimated to cost $200-$300 on the vessel and $350 onshore, excluding masting towers and guy wires. The optional external power amplifier would be approximately $500. Should a customer provide the computer, approximately $5,000 credit is given on the Path Analyzer (Swanson, S., personal communication).

II Morrow Inc. Vehicle Tracking System

The II Morrow VTS is a Loran-C based system that monitors the location and movement of a fleet of vehicles or vessels from a command center. Each vessel carries a II Morrow Loran Receiver, often tied into the existing radio transceiver. The receiver picks up positioning signals from the regional network. The VTS Control Console polls the vessels in turn using the base station transmitter at the Control Center. The on-board transceiver responds with its current location. The VTS Control Console receives the digital signal, processes and feeds it into a high resolution color TV monitor on which a map of the area is shown for visual display. Any area of the map can be magnified for greater detail. Each vessel appears on

the map as a rectangle with the vessel's alphanumeric code. The method can reportedly track a fleet of any size.

The Model 202 mobile unit consists of a Loran receiver with interface modem to store data and to transmit it upon request. Where possible, the ship's radio is used for data transmission. The Model 204 Base Station consists of a computer, modem, and monitor. The latitude and longitude data from the ship are processed and displayed on a 19 in resolution monitor. The remote station polling rate can be varied from a continuous sequence to a time-delayed sequence, or be set to operate on demand only basis. A nine-button status panel (expandable to 18 digital messages) at the Control Center enables identification of the status of individual sensors. The VTS base station has an RS 232 port that allows use of an online printer, or computer-aided, data storage, or dispatch.

Also available is the Mariner 300 plotter to obtain a permanent record of the vessel's track on a nautical chart or other media. The plotter converts Loran LOP's to latitude and longitude position with an internal microprocessor. Up to 48 way points can be entered in LOP's or latitude and longitude coordinates. The plotter can draw hyperbolic LOP grids. Scaling ranges from 1 to 999 nautical mi.

The Model 202 mobile unit ranges from $500 to $800 depending upon power requirements and frequency bands. Radio cost, if required, is approximately $700. The Model 204 Base Station cost is $18,960. In addition, the Base Station radio transmitter is approximately $1,000 with an additional estimated $1,000 to $2,000 for an antenna. The high resolution monitor is $4,200 and the Mariner 300 Track Plotter cost is $3,395 (Hardy, R., personal communication).

Megapulse CORT 500

Racal Megapulse has developed a carry on-board receiver transmitter (CORT) for traffic control use by pilots of vessels as they enter the Suez Canal. A Loran-C receiver is an integral part of the CORT. The vessel's position information is transmitted to a central location (approximately

halfway through the canal) for display. The system also can be integrated into the ship's display to provide primary navigational data. The remote units are polled according to individual identification codes. Existing units carried aboard are self-contained, including battery and antenna. A version of the CORT system currently is being produced for positioning oil drilling platforms in coastal waters. The suitcase unit, when placed on the platform, transmits the rig's position during final transit and installation.

The cost of the carry on receiver/transmitter unit is approximately $11,000. The cost of the onshore station will depend upon the user's requirements and existing equipment. Megapulse can provide either a complete system, or components compatible with existing facilities (Billings, R., personal communication).

METS Inc., TRACKER

The Marine Emergency Tracking System Division of METS offers a monitoring system called the TRACKER, which provides real time tracking and surveillance of marine vessels. Components on each vessel include a Loran-C locational device and antenna, a security panel that monitors up to eight digital inputs from sensors, and a two-way UHF radio. The system can be modified to also handle analog sensor inputs. The Central Station consists of one or more receiving antennas (depending on the extent of coverage area), a receiver, two IBM PC/AT computers, a high-resolution color monitor, and a printer. One computer is used for mapping of each vessel's location and movement, as displayed on digitized maps which also show coastlines or other markers such as a dumping zone boundary. The second computer conducts the actual monitoring of sensor input data and serves as a log of historical information on each vessel or specific cruise data (i.e., departure/arrival times, cargo characteristics, operating procedures, ownership, and insurance information).

The system, primarily designed for security services, recognizes such events as fires, bilge levels, or any attempts at intrusion. Efforts to modify or disable the system also are recognized. Normal operation is

in a polling mode, with the frequency adjustable to the needs of the user. A permanent record of the Loran coordinates and/or sensor input data is maintained by retention on a floppy disk, or by use of a slow-scan video recorder.

The company is finalizing development of similar system that incorporates GPS positioning. Also, because the system can operate over cellular telephone networks, barges can essentially be monitored anywhere where such a network exists. The cost of the vessel unit is approximately $2,000, plus the cost of sensors and their installation. The cost of the Central Station is highly dependent on needs. The computers and peripheral equipment cost approximately $20,000. The costs for the antenna system (one setup in Florida now uses seven) and for digitizing the maps could range from $10,000 to $500,000 depending on area covered, and must be determined on a project specific basis (Casselman, H., personal communication).

Puget Sound Vessel Traffic Service

The Vessel Traffic Service (VTS) Radar is maintained by the U.S. Coast Guard as an integral part of the Coast Guard's effort to minimize the danger of collisions or groundings in Puget Sound. The Vessel Traffic Center (VTC) in Seattle receives radar signals from 10 strategically located radar sites providing coverage of the major traffic lanes from the Strait of Juan de Fuca to Three Tree Point south of Seattle. Most commercial vessels are required (33 CFR 161) to check in with the VTC, comply with all VTS rules, and report any changes in vessel movement. The VTC then tracks each vessel as it moves within the VTS area.

The VTS system utilizes 10 dual-channel, remotely located, AIL high resolution radar remote stations operating between 9.3 and 9.5 GHz. These systems have a 44 km (24 nmi) range with variable scales of 3.7, 7.4, 14.8, and 29.6 km (2, 4, 8, and 16 nmi). The high resolution of the targets permits detection of any size reflectors or other targets as small as 4 m^2 (43 ft^2) in heavy seas and rain clutter (Eaton Corporation 1981). Nominal accuracy of these radar are $\pm$ 1 percent of the range scale or 37 m (121 ft) at the 3.7 km (2 nmi) range scale. Bearing accuracies are $\pm$0.5 degree.

Each remotely located radar sends its information via wideband microwave link to the VTC at Elliott Bay.

The VTC can monitor any of the remotes on any range scale. Digitized maps are overlayed on the screen, and can be edited to show disposal site boundaries. A cursor permits the operator to get a position (displayed on numeric readouts) of any vessel or object on the screen. In addition, the operator can measure the distance and bearing between any two points. Disposal site use monitoring has been tested for the Fourmile Rock dump site by requiring barges to be verified within disposal area boundaries before releasing their dredge spoils. The misunderstanding between verifying that the vessel was inside the disposal site and trying to place the barge directly on the center of the site caused delays with disposal operations more than once. The tests also highlighted the problems with barge maneuverability as a limiting factor in positioning ability to any specific point versus a larger area. By outlining detailed procedures and recording requirements for both VTS operators and tug captains, this monitoring method could provide a quick verification that the vessel went into the disposal area. Limitations to this system include limited coverage of Puget Sound disposal sites and the lack of verification of disposal within the site boundaries. A check-in for a position verification at the end of the dump could reduce, but not solve, the latter problem.

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